Plant Resources of Tropical Africa

Precursor

PROTA is an international programme involving the following institutions:

- Wageningen University (WU), Department of Plant Sciences (DPW), Haarweg 333, P.O.Box 341, 6700 AH Wageningen, the Netherlands
- Agropolis International (AGROPOLIS), Avenue Agropolis, F-34394 Montpellier cedex 5, France
- Royal Botanic Gardens Kew (RBGKEW), Centre for Economic Botany, Richmond, Surrey TW9 3AB, United Kingdom
- Centre National de Semences Forestières (CNSF), 01 B.P. 2682, Ouagadougou 01, Burkina Faso
- Centre National de la Recherche Scientifique et Technologique (CENAREST), B.P. 842, Libreville, Gabon
- Forestry Research Institute of Ghana (FORIG), KNUST, University P.O.Box 63, Kumasi, Ghana
- Parc Botanique et Zoologique de Tsimbazaza (PBZT), B.P. 4096, Tsimbazaza, Antananarivo 101, Madagascar
- National Herbarium and Botanic Gardens of Malawi (NHBGM), P.O.Box 528, Zomba, Malawi
- Makerere University (MU), Department of Botany, P.O.Box 7062, Kampala, Uganda
- Prosea Foundation (PROSEA), P.O. Box 332, Bogor 16122, Indonesia

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Plant Resources of Tropical Africa

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Editors: L.P.A. Oyen
R.H.M.J. Lemmens

Associate editors: S.D. Davis
M. Chauvet
J.S. Siemonsma

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# Contributors

- Getachew Aweke, P.O. Box 4278, Addis Ababa, Ethiopia (*Hagenia abyssinica*)
- H.J. Beentje, Royal Botanic Gardens, Kew, Richmond, Surrey TW9 3AE, United Kingdom (*Strophanthus kombe*)
- C. Bernard, Rés. St. Raphaël, 89 Rue des 4 Vents, 34090 Montpellier, France (*Faidherbia albida*)
- M.T. Besong, Institut de Recherche Agricole pour le Développement IRAD, Ekona, PMB 25, Buea, Cameroon (*Gnetum africanum*)
- G. Bezançon, Institut de Recherche pour le Développement (IRD), 911 Avenue Agropolis, B.P. 5045, 34032 Montpellier, Cedex 1, France (*Oryza glaberrima*)
- E. Boer, PROTA Network Office Europe, Wageningen University, P.O. Box 341, 6700 AH Wageningen, the Netherlands (*Acacia senegal*)
- L. Bonnéhin, Projet Autonome pour la Conservation du Parc National de Taï, (PACPNT), 01 B.P. 693, San Pédro, Côte d'Ivoire (*Tieghemella heckelii*)
- C.H. Bosch, Oudlaan 19, 6708 RC Wageningen, the Netherlands (*Spathodea campanulata*)
- M. Brink, PROSEA Publication Office, Wageningen University, P.O. Box 341, 6700 AH Wageningen, the Netherlands (*Pandanus utilis*, *Raphia hookeri*, *Vigna subterranea*)
- A. Charrier, Génétique et Amélioration des plantes, Ecole Nationale Supérieure Agronomique de Montpellier, 2 Place Viala, 34060 Montpellier Cedex 1, France (*Coffea eugenioides*)
- M. Chauvet, INRA Communication, 2 Place Viala, 34060 Montpellier, Cedex 1, France (associate editor)
- U.A. Dasuki, Department of Biology, Bandung Institute of Technology, Jalan Ganesha 10, Bandung 40132, Indonesia (*Pelargonium* Rosat Group)
- S.D. Davis, Centre for Economic Botany, Royal Botanic Gardens, Kew, Richmond, Surrey TW9 3AE, United Kingdom (*Kigelia africana*, associate editor)
- W. de Winter, Plevierenweide 82, 6708 BX Wageningen, the Netherlands (*Ampelopteris prolifera*)
- S. Diallo, Laboratoire de Malherbologie, ISRA/Fleuve, B.P. 240, Saint-Louis, Sénégal (*Oryza glaberrima*)
- J.C. Doran, Forestry and Forest Products, CSIRO, Queen Victoria Terrace, P.O. Box 4008, Kingston, ACT 2604, Australia (*Eucalyptus camaldulensis*)
- R.W. Dunlop, Institute for Commercial Forestry Research, P.O. Box 100281, Scottsville 3209, South Africa (*Acacia mearnsii*)
- O.M. Grace, c/o Centre for Economic Botany, Royal Botanic Gardens, Kew, Richmond, Surrey TW9 3AE, United Kingdom (*Kigelia africana*)
- John B. Hall, School of Agricultural and Forest Sciences, University of Wales, Bangor, Gwynedd LL57 2UW, United Kingdom (*Sclerocarya birrea*)
- P. Hamon, Institut de Recherche pour le Développement (IRD) / Université Montpellier III, 911 Avenue Agropolis, BP 5045, 34032 Montpellier, Cedex 1, France (*Dioscorea cayenensis*)

- S. Hamon, Institut de Recherche pour le Développement (IRD), 911 Avenue Agropolis, B.P. 5045, 34032 Montpellier, Cedex 1, France (*Abelmoschus caillei*)
- P.C.M. Jansen, PROSEA Publication Office, Wageningen University, P.O. Box 341, 6700 AH Wageningen, the Netherlands (*Aframomum corrorima, Hagenia abyssinica*)
- B.T. Kang, Department of Crops and Soil Sciences, University of Georgia, Athens, GA 30602, USA (*Dactyladenia barteri*)
- D.O. Ladipo, Centre for Environment, Renewable Natural Resources Management, Research and Development (CENRAD), 5 Akinola Maja Avenue, P.M.B. 5052, Jericho Hills, Ibadan, Nigeria (*Dactyladenia barteri*)
- R.H.M.J. Lemmens, PROTA Network Office Europe, Wageningen University, P.O. Box 341, 6700 AH Wageningen, the Netherlands (*Connarus africanus, Indigofera arrecta, Lycopodiella cernua, Oreobambos buchwaldii, Tieghemella heckelii*, editor)
- R.N. Lester, Birmingham University Botanic Gardens, Winterbourne, 58 Edgbaston Park Road, Birmingham, B15 2RT, United Kingdom (*Solanum aethiopicum*)
- A. Nikiema, Centre National de Semences Forestières, 01 B.P. 2682, Ouagadougou, Burkina Faso (*Vitellaria paradoxa*)
- I.C. Onwueme, Center for Sustainable Living, Wilson College, Chambersburg, PA 17201, USA (*Dioscorea cayenensis*)
- L.P.A. Oyen, PROTA Network Office Europe, Wageningen University, P.O. Box 341, 6700 AH Wageningen, the Netherlands (*Crambe hispanica, Ozoroa insignis*, editor)
- G. Pearman, PROTA Country Office UK, Centre for Economic Botany, Royal Botanic Gardens, Kew, Richmond, Surrey TW9 3AE, United Kingdom (*Dodonaea viscosa*)
- G.M. Ramolemana, Department of Crop Science and Production, Botswana College of Agriculture, Private Bag 0027, Gaborone, Botswana (*Vigna subterranea*)
- R.R. Schippers, Horticultural Development Services LLP, 19 Travertine Road, Walderslade, Chatham, Kent ME5 9LQ, United Kingdom (*Gnetum africanum*)
- G.H. Schmelzer, PROTA Network Office Europe, Wageningen University, P.O. Box 341, 6700 AH Wageningen, the Netherlands (*Ravenala madagascariensis*)
- A. Seck, Horticonsult, B.P. 26130, P. Assainies, Dakar, Sénégal (*Solanum aethiopicum*)
- K.P. Sibuga, Department of Crop Science and Production, Sokoine University of Agriculture, P.O. Box 3005, Morogoro, Tanzania (*Vigna subterranea*)
- J.S. Siemonsma, PROTA Network Office Europe, Wageningen University, P.O. Box 341, 6700 AH Wageningen, the Netherlands (*Abelmoschus caillei*, associate editor)
- S. Sina, Centre National de Semences Forestières (CNSF), 01 B.P. 2682, Ouagadougou 01, Burkina Faso (*Parkia biglobosa*)
- M.M. Spitteler, Het Hoge Stuk 19, 8431 KL Oosterwolde, the Netherlands (illustrations)

- Iskak Syamsudin, PROSEA Network Office, P.O.Box 234, Bogor 16122, Indonesia (illustrations)
- L. 't Mannetje, Eekhoornlaan 14, 6705 CH Wageningen, the Netherlands (*Alysicarpus ovalifolius*)
- S.A. Traoré, Centre National de Semences Forestières (CNSF), 01 B.P. 2682, Ouagadougou 01, Burkina Faso (*Parkia biglobosa*)
- A. Tsegaye, Awassa College of Agriculture, Debub University, P.O. Box 5, Awassa, Ethiopia (*Ensete ventricosum*)
- B.E. Umali, Crops Research Division, PCARRD, UP Los Baños, P.O.Box 425, College, Laguna 4030, the Philippines (*Vitellaria paradoxa*)
- H.A.M. van der Vossen, Steenuil 18, 1606 CA Venhuizen, the Netherlands (*Catha edulis*)
- A.P.M. van der Zon, DGIS/DML/BD, Ministry of Foreign Affairs, P.O. Box 20061, 2500 EB The Hague, the Netherlands (*Diheteropogon amplectens*)
- S. van Otterloo-Butler, Bowlespark 21, 6701 DR Wageningen, the Netherlands (English language correction)
- J.L.C.H. van Valkenburg, PROSEA Publication Office, Wageningen University, P.O. Box 341, 6700 AH Wageningen, the Netherlands (*Aucoumea klaineana*)
- E.W.M. Verheij, Edeseweg 72, 6721 JZ Bennekom, the Netherlands (*Dacryodes edulis*)
- P. Verhey-Hayes, Edeseweg 72, 6721 JZ Bennekom, the Netherlands (illustrations)
- W. Wessel-Brand, Biosystematics Group, Wageningen University, Generaal Foulkesweg 37, 6703 AH Wageningen, the Netherlands (illustrations)
- E. Westphal, PROSEA Publication Office, Wageningen University, P.O. Box 341, 6700 AH Wageningen, the Netherlands (*Ensete ventricosum*)
- W. Wongkaew, Department of Botany, Faculty of Science, Kasetsart University, Chatusak 10903, Bangkok, Thailand (*Eucalyptus camaldulensis*)

# PROTA Multilateral Steering Committee and Personnel

## Multilateral Steering Committee

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R.H.M.J. Lemmens, Editor
L.P.A. Oyen, Editor
G.C.P. Schaafsma, Databank Manager
G.H. Schmelzer, Africa Coordinator

# 1 The PROTA Programme

PROTA stands for 'Plant Resources of Tropical Africa' and is an international programme focused on the 7000 plant species used by man in Tropical Africa.
Tropical Africa for the purpose of PROTA includes the 47 countries situated for the greater part between the Tropics of Cancer and Capricorn (see Map of Tropical Africa). For the geographical definitions, PROTA adheres to the regional subdivision and country names applied by CTA (Technical Centre for Agricultural and Rural Cooperation ACP–EU), Wageningen, the Netherlands.
The great majority of the more than 500 million people in this vast area of about 22.5 million $km^2$, depend on the plant cover, the useful plants in particular, for their survival and well-being.
For the uncultivated flora, several regions and countries in Tropical Africa are in the favourable position of possessing former and current floristic works that provide excellent basic taxonomic information. However, a modern multidisciplinary Information Base providing comprehensive information on the useful plants, both cultivated and growing wild, is lacking for Tropical Africa.
The PROTA Programme has similar objectives to those of the PROSEA Programme, which successfully described the 7000 Plant Resources of South-East Asia during the period 1985–2002.

## 1.1 Objective

The objective of the PROTA Programme is simple and well-defined, though ambitious: to survey the existing knowledge on the useful plants of Tropical Africa, to critically review, summarize and publish the information in both English and French, and to make the reviews widely available for users in education, research, extension and industry.
The objective is based on the following considerations:

- thousands of plant species in Tropical Africa provide food, fibre, pharmaceutical products, building materials, utensils and fuel, for personal use and for sale in local, regional or international markets.
- an estimated 7000 species are involved.
- knowledge of these plants is indispensable for sustainable ecosystem management and rural development.
- existing information is stored in an overwhelming amount of literature which has become inaccessible for the individual user, partly because of its sheer volume, partly because of its dispersion in time and space.
- this knowledge concerns not only the botany and distribution of the plants, but also their use, ecology, husbandry, silviculture, harvesting, yield and processing, their chemical, physical, pharmaceutical and technical properties, as well as their economic and social importance, nutritional value, genetic resources, breeding and prospects.

## 1.2 Target groups

The direct users of the PROTA Information Base, the target group in a narrow sense, are all those in Tropical Africa who are professionally concerned with the plant resources and are sufficiently educated to handle scientific information in English or French. In practice, these will be people working in agricultural, forestry and botanical education, extension, research and industry.
The indirect users, the target group in the wider sense, are people in Tropical Africa who depend on the plant resources for their survival or livelihood, but who have not had adequate education to read and interpret the PROTA Information Base and have to obtain this knowledge through education and extension, for instance through specially prepared products derived from the PROTA Information Base.

## 1.3 Output

The main element of the PROTA Information Base is a collection of standardized up-to-date review articles on individual plant resources, newly written by a large number of contributing scientists.
The compilation of the review articles will be facilitated by a number of supporting databases such as BASELIST (a reference list of African plant resources and their uses), EXPERTISE (a directory of specialists), WORLDREFS (international references) and AFRIREFS ('grey' literature references from Tropical Africa).

### *1.3.1 Internet publication*

Access to Internet is already well established in the industrialized world and is fast becoming more common in other parts of the world. Although at present access in many parts of Africa is still limited, little doubt exists that this will rapidly improve in the coming years.
All texts of the PROTA Information Base will be stored in a database that will be searchable via Internet at http://www.prota.org. The database software selected, Inmagic DB/Text, offers facilities both for structured searches and free text searches. The full texts will be complemented with line drawings, colour photographs and geographic distribution maps.

### *1.3.2 Handbook*

In the PROTA Handbook the plant resources will be treated in 16 volumes each representing a commodity group. The 16 volumes together will cover an estimated 7000 species, 2500 line drawings and 2500 geographic distribution maps in about 11,000 pages.

## 1.4 Programme phasing

The First PROTA International Workshop (September 2002), discussing the organization of the PROTA Programme on the basis of some sample products and working

documents, is the highlight of the PROTA Preparatory Phase 2000–2002.
The PROTA Network, consisting of two coordinating offices (Kenya and the Netherlands), six regional nodes in Africa (Ghana – English-speaking West Africa, Burkina Faso – French-speaking West Africa, Gabon – Central Africa, Uganda – East Africa, Malawi – Southern Africa, Madagascar – Indian Ocean Islands), and two nodes in Europe (France and United Kingdom), became operational in 2002. It is ready for full implementation of the programme, which is expected to take 10 years (2003–2012).
During the First Implementation Phase 2003–2007 emphasis will be primarily on building the PROTA Information Base: 50% of all species accounts or half of the Commodity groups. This will be facilitated by the information gathering (supporting databases) in the PROTA Network.
The Second Implementation Phase 2008–2012 will see a reorientation of the PROTA Network from information gathering to dissemination of information for the indirect beneficiaries through derived products. In addition the remaining 50% of the species accounts will be completed.

### 1.5 PROTA in short

The PROTA Programme is an INTERNATIONAL undertaking, focused on African plant resources. It gives many specialists of the plant resources of the African continent the opportunity to participate in its various activities, not only in the formal network described above (information gathering, distribution and dissemination), but also in the informal network (authorship, editorship).
PROTA is INTERDISCIPLINARY by nature, covering a range of fields including agriculture, horticulture, forestry, botany, pharmacognosy, processing technology. The interplay between these disciplines is important to arrive at comprehensive review articles.
PROTA is a RESEARCH programme evaluating existing knowledge on thousands of species. Most international research deals with a small number of widely grown crops. Restricting research to familiar crops may diminish possible new developments in agriculture and forestry.
The PROTA programme is ECOLOGICALLY focused on promoting plant resources as a basis for sustainable tropical land-use systems. While many studies on ecosystem management approach the issue at a high level of integration, PROTA provides information on the elements that make up the ecosystem and that provide a livelihood for people.
PROTA is committed to the CONSERVATION OF BIODIVERSITY by providing information on the threats and conservation status of individual species.
Finally, PROTA is committed to RURAL DEVELOPMENT through diversification of resources and application of farmers' knowledge. PROTA will actively encourage the translation of scientific knowledge into practical knowledge at the local level in order to contribute to poverty alleviation.

# 2 The PROTA Information Base

## 2.1 Commodity grouping

The huge task of compiling and publishing information on 7000 species of useful plants has to be broken down into manageable units. For this purpose PROTA has adopted a division into commodity groups. This approach does not require a detailed general picture of all groups in advance and groups can be worked on separately. Classification by commodity group also has the advantage that the editorial team working on the group can better handle aspects specific to that group. General aspects of a group can be treated in an Introduction to the printed publication or a background paper in the PROTA Information Base. For example, fruits and vegetables are often grown in home gardens. Texts on fruit or vegetable species would obviously be linked to a chapter on the system of home gardening, with its scope and limitations. Similarly essential-oil plants and spices will be linked to a chapter on the extraction, chemistry and use of aroma materials. A disadvantage of this approach, however, is that many plants have several uses and could be included in several groups. Cassava, for example, is primarily a root crop yielding carbohydrates, but it is also a vegetable and a forage crop. To avoid duplicate work, species will be treated only once, in accordance with their primary use. Care will be taken to include and elaborate all uses in that treatment.
The following 16 Commodity groups have been distinguished:

PROTA 1: Cereals and pulses
PROTA 2: Vegetables
PROTA 3: Dyes and tannins
PROTA 4: Ornamentals
including hedge and wayside plants and plants used for amenity planting
PROTA 5: Forages
including pasture plants
PROTA 6: Fruits
including nuts
PROTA 7: Timbers
including bamboos
PROTA 8: Carbohydrates
including root and tuber crops, sugar and honey plants, sago and other starch yielding plants
PROTA 9: Auxiliary plants
including plants grown as shade or cover plant in agriculture, including mulches and green manures and plants grown as fences
PROTA 10: Fuel plants
including plants used for making charcoal
PROTA 11: Medicinal plants
including poison plants, plants yielding narcotics, insecticides

PROTA 12: Spices and condiments
PROTA 13: Essential oils and exudates
including plants yielding aromatic resin or aromatic wood, plants exuding rubber, latex or gum, and plants producing resin, camphor, balsam or wax
PROTA 14: Vegetable oils
including plants yielding edible and non-edible oils and fats and related substances
PROTA 15: Stimulants
including plants used for beverages, chewing and smoking
PROTA 16: Fibres
including rattans and plants used for making baskets, mats and wickerwork or for packing or thatching

Plants with religious, ceremonial or cultural uses are grouped under one of their other uses, e.g. palaver trees also yield timber or forage.

## 2.2 Species

The PROTA 'Basic list of species and commodity grouping' (2002) provides a provisional list of 6400 species for the PROTA databank and provides editors with a checklist of the species to be considered. The PROTA 'Basic list of species and commodity grouping' was compiled on the basis of 13 publications which together give a good overview of the useful plants of Tropical Africa. PROTA editors will make a first selection of species of a commodity group on the basis of the 'Basic list'. They will adapt and update the list on the basis of literature surveys and their own experience. PROTA intends to give a comprehensive overview of the useful plants of Africa. Mode of treatment is not only determined by the economic importance but also by the prospects of species that have not yet assumed much importance or that have important agronomic or ecological characteristics.

## 2.3 Method of treatment

The treatments of plant species in the PROTA Information Base will follow a set format. All texts start with an identification of the species, followed by sections on origin and geographic distribution, uses, production and international trade, properties, botany, ecology, management, genetic resources and breeding, prospects and literature references. An extended format will be used for major species; for lesser-known species a reduced format will be used in which certain sections from the extended format have been combined, to avoid splitting up the little information available and improve readability. For major species a botanical drawing and a distribution map will be added to the printed text, to electronically published text also a maximum of 5 photographs. The proportion of major species treated in accordance with the extended format is about 35%. For accounts of major species external authors will be invited, preferably one per paper. In principle, the papers on lesser-known plants will be written by the editorial team.

## Format of PROTA species accounts

| Major species – extended format | Lesser-known species – reduced format |
|---|---|
| Botanical name | Botanical name |
| Protologue | Protologue |
| Family | Family |
| Chromosome number | Chromosome number |
| Synonyms | Synonyms |
| Vernacular names | Vernacular names |
| Origin and geographic distribution | Origin and geographic distribution |
| Uses | Uses |
| Production and international trade | Production and international trade |
| Properties | Properties |
| Adulterations and substitutes | |
| *Botany* | Botany |
| Description | |
| Other botanical information | |
| Anatomy | |
| Growth and development | |
| Ecology | Ecology |
| *Management* | Management |
| Propagation and planting | |
| *In vitro* production of active compounds | |
| Management | |
| Diseases and pests | |
| Harvesting | |
| Yield | |
| Handling after harvest | |
| *Genetic resources and breeding* | Genetic resources and breeding |
| Genetic resources | |
| Breeding | |
| Prospects | Prospects |
| Literature | Literature |
| Major references | Major references |
| Other references | Other references |
| Sources of illustration | |
| Authors | Authors |

Comments on the format
- botanical name: scientific name; abbreviation and spelling of author's names is in accordance with Brummitt & Powell (1992): 'Authors of plant names'.
- family.
- chromosome number.
- protologue: original publication of the name.

- synonyms: only the most commonly used synonyms and those that may cause confusion are mentioned.
- vernacular names: although vernacular names are very important for identification, it is beyond the scope of PROTA to give an extensive overview of the names of a plant in all languages spoken in its area of distribution. Only names in languages spoken in several African countries are included: English, French, Portuguese and Swahili. Although national forms of Arabic are spoken in several countries in Africa, the number of African plants that have a name in written, classical Arabic is limited. Arabic names are therefore omitted.
  Names of plant products are mentioned under uses.
- origin and geographic distribution: distribution in the world and in tropical Africa is given. To avoid long lists of countries in the text, a map is added to the treatments of the major species. The map indicates in which countries a species occurs, either naturally or in cultivation.
- uses: the primary use and secondary uses in Africa and elsewhere are mentioned. Although the work of PROTA is organized around commodity groups, care will be taken to give due attention to all uses. Medicinal uses have been reported for the majority of the useful plants of Africa. PROTA recognizes the importance of traditional medicinal knowledge of plants, but is reluctant to give a mode of authority by repetition. Therefore, the importance of a species in medicine and its major uses will be mentioned, but no attempt will be made to be exhaustive.
- production and international trade: area cultivated, production and value, local consumption or use, and amount exported are indicated.
- properties: chemical composition, nutritional value, toxicity, physical and technical properties are given. Texts will be concise, but sometimes details of extraction or analysis have to be given, e.g. for pharmacological tests.
- adulterations and substitutes: products, often synthetic ones, used or traded as cheap alternatives or additives are mentioned.
- description: a morphological characterization of the species is given. For accuracy, the description is fairly detailed. A line drawing is added for major species to complement the description. In electronic publications, photographs are provided where possible.
- anatomy: information is only given when important for the characterization of plant products, especially for wood.
- other botanical information: taxonomic relations and relevant subclassifications with characteristics are indicated.
- growth and development: germination, vegetative and generative development, pollination and seed dispersal are treated.
- ecology: climatic factors, soils and vegetation of the natural habitat are given.
- propagation and planting: methods of propagation, tissue culture, nursery management, handling of planting material and plant densities are discussed.
- *in vitro* production of active compounds.
- management: covers a wide range of activities that may include cropping system, rotations, stand establishment, weeding, staking, pruning, irrigation, fertilizers, mulching, shading.
- diseases and pests: diseases and pests of economic importance are given with their symptoms and control measures.

- harvesting: time or period and methods of harvesting are indicated.
- yield: average yield and range under various conditions of ecology and management are mentioned.
- handling after harvest: activities include transport, storage, grading, packing and first processing.
- genetic resources: for wild species, genetic variability and where relevant threat of genetic erosion or even extinction are indicated; for crops, variability and collections of germplasm.
- breeding: useful genetic stock, major cultivars or cultivar groups and recent research achievements are mentioned.
- prospects: possibilities of continued or expanded use or cultivation are discussed, and research priorities are indicated.
- literature: the main objective of the list of references is to guide readers to additional information. There is no intention to give a complete list of references. The method of working of PROTA makes it difficult to refer to literature in the text, because editors, associate editors and general editors do not always have access to all literature used by authors; authors or editors will select major and other references; major references are limited to 10 references for further reading, other references to a maximum of 20 additional references.

In planning the PROTA Information Base, 6 categories for length of treatment have been considered: less than 1 page, 2, 3, 4, 5 pages; a very limited number of important crops may have longer treatments of up to 8 pages. It is estimated that 4500 lesser-known species need a total of 3000 pages, and that 35% of the major species will have a 2-page treatment, 30% 3 pages, 20% 4 pages 10% 5 pages and 5% 6 or more. The complete Information Base will then comprise about 11,000 printed pages.

A line drawing will be added to all treatments of major species. As the text is printed in 2 columns the drawing has to be small, while on Internet speed of transfer also requires simple drawings. The illustrations are intended to give a general impression of the plant and only the most important details. On Internet a maximum of 5 colour photographs will be added.

## 2.4 Writing and editing process

Compiling information on 7000 plant species, critically reviewing and summarizing this in review articles is a huge task that can only be successfully completed with the active cooperation of a large number of scientists. PROTA relies on a large informal network of authors and editors from all over the world and it intends to invite 2 editors for each commodity group who will be responsible for the scientific content of the group, under the responsibility of the general editors, and if necessary, in cooperation with associate editors covering specific aspects. The tasks of the editors will be:

- to advise the general editors about the selection of species to be included in the group and about their relative importance.
- to advise the general editors about authors to be invited to write the texts for the species selected.

- to write an introductory chapter dealing with general aspects of the commodity group. The editors may, as a matter of course, also write part of the species treatments.
- to critically review the complete set of manuscripts of the group in close cooperation with and under the final responsibility of the general editors.

The 'PROTA Basic list of species and commodity grouping' is the starting point for the selection of species, but editors will prepare the list of species belonging to the commodity group. As many species have several uses, and consequently several commodity group editors may claim a species, the general editors will draw the lines. The final lists may deviate from the 'Basic list'. This is illustrated by some of the papers in this Precursor: *Dodonaea viscosa* is classified in the 'Basic list' in the commodity group 'Auxiliary plants', but its primary use is determined as 'Medicinal plant' on the basis of the Precursor text. *Abelmoschus caillei*, which was distinguished from *Abelmoschus esculentus* only recently, is not included in the 'Basic list' although it is an important vegetable in West Africa. *Coffea eugenioides* is also not included in the 'Basic list'.
Editors will be assisted by the Network Office Africa and the Network Office Europe to identify potential authors and to obtain literature references on the species of their commodity group. As PROTA texts will follow a set format, authors will be given detailed guidelines about the structure, length and presentation of their contribution. On request authors will be provided with literature references from WORLDREFS and AFRIREFS. Authors are requested to provide photographs and material for a line drawing of the species concerned. Authorship is governed by a simple contract regulating copyrights and author fee.
The drawings will be redrawn from existing illustrations by PROTA illustrators.

## 2.5 Precursor

The Precursor has been made as a sample of the PROTA Information Base for a discussion on form and contents. It presents texts and illustration materials on a selection of 39 species of varying economic importance and representing all commodity groups. Most texts in this Precursor follow the extended format, only four texts on lesser-known plants follow the reduced format.
Many texts of this Precursor have been written by staff of the PROTA Network Office Europe. They were written when the PROTA Network was still in its infancy. The proportion of African authors will be much greater in future PROTA publications.
In the volumes of the PROTA Handbook, a glossary explaining all specialist terms and indexes of scientific names and vernacular names will be added. They have been omitted from this Precursor for practical reasons only.

# 3 Alphabetical treatment of species

## ABELMOSCHUS CAILLEI (A.Chev.) Stevels

**Protologue** Bull. Mus. natn. Hist. nat., Paris, sér. 4, 10, sect. B, Adans., 2: 138 (1988).

**Family** Malvaceae

**Chromosome number** $2n = 184–200$

**Synonyms** *Hibiscus manihot* L. var. *caillei* A.Chev. (1940), *Hibiscus manihot* auct. non L., *Abelmoschus manihot* auct. non (L.) Medik., *Hibiscus esculentus* auct. non L., *Abelmoschus esculentus* auct. non (L.) Moench.

**Vernacular names** West African okra, West African okro (En). Gombo ouest-africain, gumbo ouest-africain (Fr). In African languages it is sometimes referred to as 'late okra' or 'dry-season okra'.

**Origin and geographic distribution** The genus *Abelmoschus* originated in South-East Asia. West African okra, however, is a cultigen occurring mainly in West and Central Africa. It has been reported from Guinea to Nigeria in West Africa, in Cameroon, Gabon and the Democratic Republic of Congo in Central Africa, and in Uganda in East Africa. Its distribution is restricted to humid and perhumid climates in Africa, between 12°N and 12°S, most commonly between 5°N and 10°N, whereas the common okra (*Abelmoschus esculentus* (L.) Moench) can be found worldwide throughout the tropics, subtropics and warm temperate regions.

**Uses** Young immature fruits are an important vegetable, consumed raw, cooked or fried. In West Africa, they are usually boiled in water to make slimy soups and sauces, which are relished. Fruits can be dried, whole or sliced, and subsequently preserved. Before selling, the dried product is usually ground to a powder. Young leaves are sometimes consumed as spinach.

*Abelmoschus caillei - planted.*

There are no apparent differences in uses between West African and common okra. The extent to which the uses mentioned below apply to West African okra is unknown. Leaves are considered good cattle feed, but this is seldom compatible with the plant's primary use for human consumption. Okra mucilage is suitable for medicinal and industrial applications. It has been used as a plasma replacement or blood volume expander. Leaves are sometimes used as a basis for poultices, as an emollient, sudorific, antiscorbutic and to treat dysuria. Okra mucilage has been added as size to glaze certain papers, and is used in confectionery. The bark contains a fibre which is suitable for spinning into rope and for paper and cardboard manufacture. The fibre has been locally used for fish-lines and game-traps, but fibre harvesting is incompatible with fruit harvesting. Roasted seeds of okra are used in some areas as a substitute for coffee.

**Production and international trade** World production of okra (both species) as fresh fruit-vegetable is estimated at 6 million t/year. Okra production in West and Central Africa is estimated at 500,000–600,000 t annually based on available consumption data. West African okra is estimated to make up half this amount, about 5% of total world production of okra.

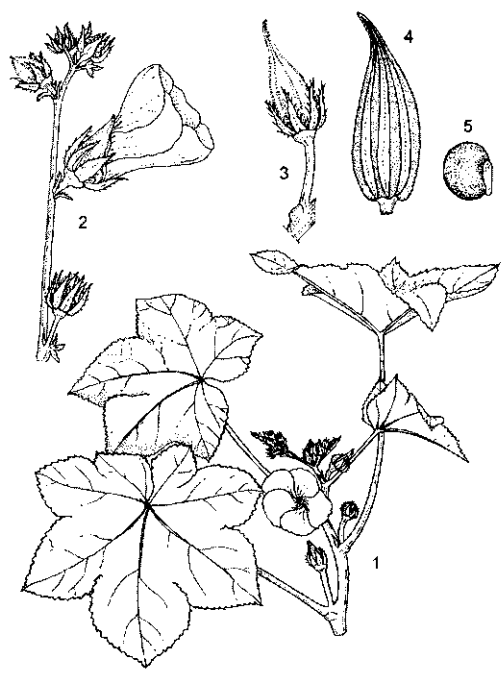
**Properties** No studies suggest systematic differences in nutritional value between the two okra species. Per 100 g edible portion, fresh okra fruit contains: water 90 g, protein 2.0 g, fat trace, carbohydrates 6.0 g, fibre 1.0 g, Ca 70 mg, Fe 1.0 mg, vitamin A 150 I.U., thiamine 0.1 mg, riboflavin 0.1 mg, nicotinic acid 1.0 mg, vitamin C 25 mg. The energy value is 140 kJ/100 g. Carbohydrates are mainly present in the form of mucilage. That of the young fruits of *Abelmoschus esculentus* consists of long-chain molecules with a molecular weight of about 170,000 made up of sugar units and amino acids. The main components are galactose (25%), rhamnose (22%), galacturonic acid (27%) and amino acids (11%). The mucilage is highly soluble in water. Its solution in water has an intrinsic viscosity value of about 30.

Okra seeds contain about 20% protein (similar in amino acid composition to soybean protein) and 20% oil (similar in fatty acid composition to cotton-seed oil). The bark fibre is easy to extract. It is white to yellow in colour, strong but rather coarse.

Tests conducted in China suggest that an alcohol extract of *Abelmoschus* leaves can eliminate oxygen free radicals, alleviate renal tubular-

interstitial diseases, improve renal function and reduce proteinuria.

**Description** Stout, annual to biennial, erect herb up to 4 m tall, mostly strongly branched; stem often woody at base, terete, glabrous or with scattered, stiff hairs, glabrescent, often red-blotched; branches erect to curved downwards. Leaves arranged spirally, simple, variable in shape and size; stipules filiform, up to 20 mm long, covered with stiff hairs, especially on the margins; petiole up to 60 cm long, often red-tinged, with a line of soft, simple hairs on the upper side, otherwise glabrous or with scattered, stiff hairs and glabrescent; blade transversally elliptical to orbicular in outline, up to 50 cm broad, length of midrib up to 35 cm, mostly 3-, 5- or 7-palmatilobed to palmatipartite, cordate at base, 5–9-veined, segments triangular, ovate, elliptical, obovate, oblong, spatulate or lanceolate, acuminate, serrate to crenate, sometimes entire or angular, veins on both sides with scattered, stiff hairs, glabrescent. Flowers axillary, solitary or racemose by reduction or abortion of the upper leaves; pedicel up to 4.5 cm long in flower, up to 13 cm in fruit, glabrous or with scattered, stiff hairs, glabrescent; epicalyx segments 5–10, free, ovate to oblong, 10–35 mm × 4–13 mm, acute to acuminate, generally persistent through early fruit, covered with stiff hairs, especially on the margins; calyx spathaceous, 2–7 cm long, 5-toothed apically, usually splitting on one side at the expansion of the corolla, adnate to and caducous with the corolla and staminal column, sericeous outside, often mixed with short, simple and stellate hairs, strigose to sericeous inside; petals 5, free, obovate to orbicular, 4–9 cm long, base fleshy, apex obtuse to retuse, glabrous, yellow, often turning pink after anthesis, with a dark purple centre; stamens united into a staminal column up to 3.5 cm long, white, glabrous; ovary superior, tomentose, often with some stiff hairs on the costae as well, 5–12 style arms 3–5 mm long, stigmas dark purple, with simple hairs. Fruit an erect to drooping, ovoid capsule 5–25 cm × 1–5 cm, acuminate, terete to 5–12-angled, concave between the costae, gradually losing its original indumentum, when young varying in colour from purple-red and reddish-green to dark green, and from pale green to yellow, completely or partially loculicidal or not opening at all, up to 100-seeded. Seeds globose to ovoid, 3–5 mm in diameter, with minute warts in concentric rows, rarely with long red hairs on the seed coat.




*Abelmoschus caillei – 1, top of flowering plant; 2, flowering branchlet; 3, young fruit; 4, mature fruit; 5, seed.*
*Redrawn and adapted by W. Wessel-Brand.*

**Other botanical information** This taxon was described as a species in 1988 although it is only known from cultivated material. A classification as cultivar group might have been more appropriate.

There are strong indications that *Abelmoschus caillei* is an amphidiploid of *Abelmoschus esculentus* (L.) Moench ($2n$ = 130–140) and *Abelmoschus manihot* (L.) Medik. ($2n$ = 60–68). However, the latter species has not been found with certainty in the area of distribution of West African okra, and isozyme analysis has neither confirmed nor rejected the relationships. *Abelmoschus manihot* differs from *Abelmoschus caillei* by a smaller number of epicalyx segments (4–8), and much smaller fruits (3.5–6 cm long) which are inedible because they are covered with prickly hairs.

*Abelmoschus esculentus* differs in several respects from *Abelmoschus caillei*, but the epicalyx offers the best discriminating characteristic: the width of the epicalyx segments is 4–13 mm in *Abelmoschus caillei* and 0.5–3 mm in *Abelmoschus esculentus*.

The two okra species can be quite reliably (but not with absolute certainty) recognized on the basis of fruit form. Fruits of *Abelmoschus caillei* are ovoid, whereas fruits of *Abelmoschus esculentus* are cylindrical to pyramidal.

The list of synonyms shows that information related to *Abelmoschus caillei* has often been attributed to *Abelmoschus esculentus* and/or *Abelmoschus manihot*, thus literature has to be interpreted with care.

**Growth and development** Germination of West African okra is epigeal. Under the conditions of southern Côte d'Ivoire (5°N), it flowers within 50–110 days after sowing in the dry season (sowing in October: days shortening) and within 65–270 days after sowing in the rainy season (sowing in March: days lengthening). The short-day types, planted at the beginning of the rains (March), do not flower by the end of the rainy season (November), but are vegetatively so well-developed that they easily survive the dry season without supplementary water, and flower and bear fruit in a period of scarcity. Crop duration thus shows enormous variation depending on cultivar, locality and season, and varies from 4 months to well over 12 months.

Comparing cultivars of similar earliness, it is striking that West African okra has a considerably longer productive period than cultivars of common okra. This is an attractive feature for home garden planting.

Flower opening and pollination take place in the early morning. Although basically a self-pollinated crop, considerable cross-pollination by insects may take place. For vegetable use the fruits are picked about one week after anthesis. The regular removal of young fruits permits sustained vegetative growth and flowering, prolonging the productive period. In a seed crop, it takes about one month from anthesis to fruit maturity. In this case, vegetative growth stops soon after anthesis, all assimilates being diverted to reproductive parts.

**Ecology** Many local types show a qualitative short-day response even at a latitude of only 5°, the shortest critical daylength reported being 12 hours 15 minutes. Even at this latitude, vegetative periods of 8–9 months occur when sown under the 'long-day' conditions of the rainy season. Apart from these qualitative responses, most local types show quantitative short-day responses. West African okra is, therefore, not suitable for semi-arid and arid regions beyond latitudes of 12°N and 12°S because of daylength requirements.

West African okra tolerates a wide variety of soils but prefers well-drained sandy loams, with pH 6–7, and a high content of organic matter.

**Propagation and planting** Propagation is by seed. Seed weight varies from 30–70 g/1000 seeds. Most farmers harvest seed from their own local cultivar or rather heterogeneous landrace. The easiest way to keep the seed is to leave it in the pods. Prior to sowing it is often soaked in water to soften the hard seed coat. The seed is usually dibbled directly in the field (1–3 seeds per hole). The robust West African okra should be grown at 20,000–50,000 plants/ha. Emergence is within one week. When the plants are about 10 cm tall, they are thinned to one plant per hole.

Germination and initial growth are improved greatly by cultural practices that lower soil temperature, e.g. mulching, watering before the hottest part of the day, and sowing on ridge sides least exposed to direct sunlight.

**Management** Commercial okra growers usually practise sole cropping, and prefer the early, homogeneous, introduced cultivars of common okra (*Abelmoschus esculentus*). In traditional agriculture, farmers grow their okra landraces in home gardens or in fields with other food crops. The landraces often consist of a mixture of *Abelmoschus caillei* and *Abelmoschus esculentus*, the former being predominant in the humid climates, the latter in the drier climates.

The uptake of minerals is rather high. Indicative figures for total nutrient uptake per ha of a crop with fruit yield of about 10 t/ha are 100 kg N, 10 kg P, 60 kg K, 80 kg Ca and 40 kg Mg.

Under humid tropical conditions a full-grown crop consumes about 8 mm of water per day.

Some farmers practise ratoon cropping. A ratoon crop flowers soon after cutting, but usually results in poor quality fruit with a high percentage of bent fruits.

**Diseases and pests** West African okra is more tolerant of diseases and pests than common okra. An exception is vascular wilt, which in West African okra has more time to manifest itself due to the longer crop duration. The most serious fungal diseases of okra in West Africa are damping-off (*Macrophomina phaseoli*), vascular wilt (*Fusarium oxysporum*) and Cercospora blight (*Cercospora abelmoschi*). *Oidium abelmoschi* is more important in the drier climates.

Okra mosaic virus (OMV), transmitted by flea beetles (*Podagrica*), is widespread but damage is much less important than that caused by leaf curl, transmitted by whitefly (*Bemisia tabaci*). These viruses must be controlled through chemical control of the vectors. Nematodes of the genus *Meloidogyne* constitute a major problem. Damage by nematodes is avoided by crop rotation (e.g. with Guinea grass, *Panicum maximum* Jacq.) and by large applications of organic manure.

Insect damage is mainly due to the cricket *Brachytrupes membranaceus*, to *Podagrica*, to the bollworms *Earias biplaga* and *Pectinophora gossypiella*, and to the beetle *Anomala denuda*. Chemical control of insects is hazardous because crop harvesting is frequent.

**Harvesting** The earliest types of West African okra are ready for first harvest at 8 weeks after sowing. Developing fruits should be harvested when 7–8 days old. Earlier picking depresses yields because of low fruit weight, but delayed picking depresses marketable yields because over-aged fruits become fibrous. Okra fields are, therefore, harvested at intervals of 2–3 days. The minimum frequency is once a week but then fruits of all sizes have to be picked. Although such a low frequency reduces yield, the very small fruits can fetch a higher price, being of prime quality. For seed production, the whole crop can be harvested once-over. Intensive contact with the slightly hairy fruits and plants may lead to skin irritation.

**Yield** A vegetable yield of 10 t/ha can be considered a good harvest, but yields of over 40 t/ha can be realized under optimal conditions. Yields are usually low (2–4 t/ha) as a result of non-intensive growing methods. Seed yields are usually in the range of 500–1000 kg/ha.

**Handling after harvest** Fresh okra can be transported quite easily in bulk and kept for a few days without much loss of quality. Dried okra is an important product in West Africa.

Okra mucilage can be obtained by grinding plant material, removing waxes and fat with ether and alcohol, suspending the purified material in water, filtering and concentrating the filtrate.

**Genetic resources** Local landraces are not at great risk of genetic erosion at present. Only commercial growers tend to switch to commercial cultivars of *Abelmoschus esculentus*, whereas *Abelmoschus caillei* is ubiquitous in subsistence farming.

Substantial germplasm of West African okra is maintained by CNRA (Centre National de Recherches Agronomiques) in Bouaké (Côte d'Ivoire) and by IRD (Institut de Recherche pour le Développement) in Montpellier (France). Many national collections contain both okra species, curators often not being aware of the difference. West African okra has already been introduced into several American and Asian countries for research purposes through germplasm exchange. West African okra is reported to be resistant to yellow-vein mosaic virus (YVMV), a major cause of crop failure of common okra in Asia, whitefly (*Bemisia tabaci*) being the vector.

**Breeding** Selection and breeding of West African okra have not been carried out by the private sector, but African farmers have selected an enormous diversity of forms which fit into a great variety of cropping systems. There is, however, plenty of scope for combining desirable characteristics in cultivars for the traditional sector (where hardy, robust, long-lived types are required) as well as for the commercial sector (where good alternatives for introduced cultivars of *Abelmoschus esculentus* are needed with better adaptation to local conditions, diseases and pests in particular). Nevertheless, isozyme analysis has shown a rather low level of genetic diversity in cultivated okra in spite of much phenotypic variability.

The characteristics of both okra species open up new opportunities for recombination. They cross readily in both directions and crosses result in vigorous hybrids; these, however, show a marked reduction in fertility. Nevertheless, seed is formed by interspecific hybrids under conditions of open pollination, probably due to backcrossing with fertile pollen of one of the parental species. *Abelmoschus esculentus* 'Parbhani Kranti' was bred in this way in India, with YVMV resistance/tolerance derived from *Abelmoschus caillei*. Although occurring together in farmers' fields, the genetic integrity of the two okra species is largely assured because chances are very small that the unproductive F1 hybrids will be selected as seed sources for the next crop.

**Prospects** Okra will remain a welcome, productive fresh fruit-vegetable. The relatively recent discovery that West African okra is very different from common okra offers new possibilities in an old crop.

**Major references** 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2010, 2011

**Other references** 2013, 2014, 2016, 2017, 2018, 2019, 2020, 2021, 2022

**Sources of illustration** 2010 (top of flowering plant, seed), 2020 (flowering branchlet, young fruit, mature fruit)

**Authors** J.S. Siemonsma & S. Hamon

## ACACIA MEARNSII De Wild.

**Protologue** Pl. bequaert. 3(1): 61 (1925).

**Family** Mimosaceae (Leguminosae - Mimosoideae)

**Chromosome number** $2n = 26$

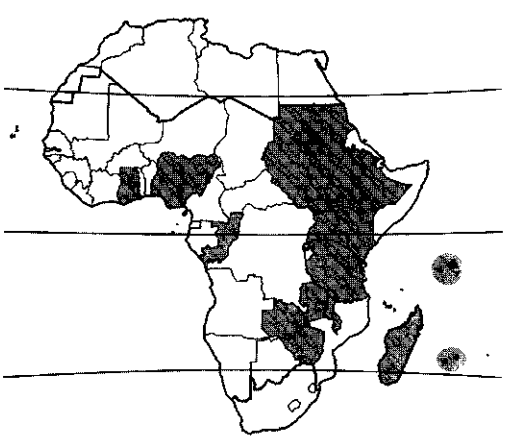
**Synonyms** *Racosperma mearnsii* (De Wild.)

Pedley (1986), *Acacia decurrens* auct. non Willd., *Acacia mollissima* auct. non Willd.

**Vernacular names** Black wattle, tan wattle (En). Acacia noir (Fr). Acácia negra (Po). Muwati (Sw).

**Origin and geographic distribution** Black wattle is native to south-eastern Australia from 35–44°S latitude (New South Wales, Queensland, Victoria and Tasmania). It has been introduced throughout the tropics and subtropics. Large commercial plantations are found in southern and eastern Africa (Kenya, South Africa and Zimbabwe), Brazil and India. Elsewhere plantings are smaller or introductions have not been successful.

**Uses** Black wattle is primarily cultivated for tannin and wood production. It is the world's principal source of tanbark; the bark contains up to 40% of excellent tannin especially suitable for use in the manufacture of heavy leather goods. In addition, the powdered bark extract is used to prepare tannin formaldehyde adhesives for exterior grade plywood, particle board and laminated timber. Possibilities of using the bark in the production of biodegradable polyurethane foam are being tested. The wood of the tree is widely used as fuelwood for domestic use and village industries, or for charcoal production (e.g. in Kenya, South Africa and Brazil). The wood may also be used for local construction material, mine props, wooden tools, joinery, flooring and hardboard. Thin, pliable stems are used in the framework of traditional wattle and daub huts by many African people. The wood is used in combination with other woods to produce paper pulp and dissolving (or viscose) pulp, the raw material used to produce synthetic fibres such as rayon. In recent years the use of black wattle wood in the pulp and paper industry has increased substantially worldwide. Japan in particular is a large importer of black wattle chips from South Africa. Black wattle is also planted for erosion control and soil improvement, as shelter belts or fire belts, as a shade tree in plantations, and as an ornamental. The leaves are sometimes used for fodder, but are relatively unpalatable and can best be mixed with other feeds. A decoction of the very astringent bark is used as a styptic and to treat diarrhoea.



*Acacia mearnsii – planted and naturalized.*

**Production and international trade** The maximum area of black wattle plantations was reached around the 1960s. Since then, a fall in demand for vegetable tannin has led to a considerable reduction in area, e.g. from 325,000 ha to 130,000 ha in South Africa and from 27,000 ha to 14,000 ha in Zimbabwe. Around 1980 the estimated plantation area was about 350,000 ha, of which 160,000 ha were in South Africa, 125,000 ha in Brazil, 30,000 ha in East Africa (Zimbabwe, Kenya, Tanzania, Rwanda, Burundi), 20,000 ha in India, and 15,000 ha in Indonesia. Black wattle is currently the world's major source of vegetable tannin, closely followed by quebracho (*Schinopsis* spp.).

In several countries, including Kenya, Zimbabwe and South Africa, tannin industries based on black wattle have been developed. South Africa also produces a variety of adhesives from the bark extracts. The main exporting countries are South Africa (30,000 t/year of tan extract and 15,000 t/year of adhesive products) and Kenya (25,000 t/year of tan extract, but the Kenyan factory has recently closed). These products are exported to many countries where niches are available for vegetable tannin extract and naturally derived adhesives.

For every 1 t of bark harvested from the trees about 5 t of timber is available. The timber is mainly traded locally. Some of the wood is converted to charcoal, part of which is exported, especially to Europe, but no production or export data are available. South Africa uses 160,000–200,000 t/year of air-dried wood in the production of dissolving pulp and exports about 800,000 t/year of air-dried chips for pulp and paper production to Japan, and 50,000–70,000 t/year of air-dry logs for pulp and paper production to Norway.

**Properties** The bark of black wattle contains 30–40% high-quality tannin on dry weight basis. The tannin belongs to the proanthocyanidins, and is a complex mixture of some 40 components; among the main constituents are (+)-catechin, (–)-

robinetinidol and (+)-gallocatechin. The tannin quickly penetrates the hide, and gives a firm and durable light-coloured leather, unlike other proanthocyanidin tanning materials (e.g. mangrove extracts) which give a reddish colour. It does not precipitate in acid solution, resulting in better quality leather. It is especially suited for the manufacture of sole leather for shoes.

The tannin content varies with bark thickness, age of the tree and average annual rainfall, and decreases from the base of the trunk upwards, the bark of the branches having a low tannin content. Black wattle extract contains 60–65% tannin. Extracts, usually called 'mimosa extract', are commercially available in several forms, each giving different qualities to leather. Usually the extract is mixed with synthetic tannins for use in the leather industry.

The wood is yellowish to pale red. Wood density ranges from 550–850 kg/m$^3$ , depending on site conditions. The wood is moderately hard to hard, durable, and fairly tough and strong. It has an energy value of about 19,700 kJ/kg and ash content of about 1.5%. The energy value of charcoal is about 32,000 kJ/kg. The density and pulp yield of black wattle make it a very attractive alternative to *Eucalyptus globulus* Labill.

**Adulterations and substitutes** Other tanning agents, such as chromium salts and synthetic tannins (syntans, resin tannages and aldehyde tannages), are nowadays mostly used for tanning leather. They have a more specific activity and are more predictable and controllable in the tanning process. Sometimes chrome tanning or tanning with synthetic tannins is combined with vegetable tanning, e.g. re-tannage of chrome-tanned leather to develop special characteristics, or the use of chrome tannins for shoe upper leather and vegetable tannins for the sole.

**Description** Small to medium-sized evergreen tree, up to 30 m tall; trunk straight, up to 50 cm in diameter; bark brownish-black, fissured, but in younger stems grey-brown and smooth; crown spreading, rounded at maturity; twigs unarmed, angled, grey, densely hairy when young. Leaves alternate, bipinnately compound, 8–15 cm long, with 8–20 pairs of pinnae 2–5 cm long; rachis with glands at base of each pair of pinnae on upper surface; leaflets very numerous, 20–70 pairs crowded on each pinna, narrowly oblong and small, 1.5–4 mm × 0.5–0.8 mm, blunt, with dense soft hairs, dark olive green. Inflorescence a globose head 5–8 mm in diameter, arranged in axillary racemes or panicles, head up to 50-flowered. Flowers bisexual, 5-merous, pale creamy-yellow, very sweet-scented; calyx lobes ca. 1 mm long; corolla lobes ca. 2 mm long, pointed at the apices; stamens 30–45, filaments up to 2.5 mm long; ovary superior, 1-celled, style long and slender. Fruit a narrowly oblong or linear, flat pod, (3–)5–10(–15) cm × 0.5–1 cm, constricted between the seeds, pubescent, dark brown to blackish when ripe, dehiscent along one suture, 3–14-seeded. Seeds ovoid, 3–5 mm × 2–3.5 mm, smooth and black, with a small yellowish-white aril.


*Acacia mearnsii – 1, flowering branch; 2, branchlet with fruits.*
*Source: PROSEA.*

**Other botanical information** There has been considerable confusion about *Acacia mearnsii* and some closely allied species: *Acacia decurrens* Willd. (green wattle) and *Acacia dealbata* Link (silver wattle). These species have long been considered as conspecific with *Acacia mearnsii*, although usually distinguished as varieties. They are now usually thought to represent distinct species. The name *Acacia mollissima* has often been used erroneously for *Acacia mearnsii*. In fact, *Acacia mollissima* Willd. is a synonym for *Acacia pubescens* (Vent.) W.T.Aiton. The name *Acacia decurrens* is still commonly used for *Acacia mearnsii*, which makes literature on these species very confusing. *Acacia mearnsii* can be

crossed with *Acacia decurrens*, *Acacia dealbata*, *Acacia baileyana* F.Muell. and *Acacia irrorata* Sieber ex Spreng. Hybrids have no real advantages over the parent species and are often partly sterile.

**Anatomy** Wood-anatomical description:
– Macroscopic characters:
Heartwood pale brown with reddish markings, indistinctly demarcated from the pale straw-coloured sapwood. Grain often interlocked. Texture moderately fine.
– Microscopic characters:
Growth rings indistinct. Vessels diffuse, 6–8/mm$^2$, in oblique or radial multiples of up to 4. Fibres 700–880 μm long and 9–21 μm in diameter. Parenchyma absent or scarce, vasicentric and aliform. Rays inconspicuous and narrower than vessels.

**Growth and development** Seeds stay viable for many years, both in storage and in the ground. Seeds in the ground start to germinate after a forest fire or land cultivation. Seedlings are susceptible to fire. On germination, the radicle grows downwards to form a taproot of about 1 m. Fast-growing lateral roots develop from the taproot just below the soil surface. Nodules formed by N-fixing bacteria usually appear on the lateral roots.
Black wattle is a light-demanding species with rapid early stem growth, reaching up to 3 m/year. Some trees start to flower when only about 2 years old. If the growing point is not damaged black wattle produces a fairly straight stem, sometimes almost circular but usually more or less elliptical in cross-section. Plantation grown trees have an average taper of 2.5 cm in 3 m, single trees show more taper. In commercial plantations in South Africa, trees at a rotation of 10 years are rarely shorter than 10 m and on good sites attain 27–30 m, with diameters at breast height seldom exceeding 30 cm. Crown shape in plantation trees usually assumes an inverted pear-shape with age, and is generally globose at maturity. Branches die progressively from below, due to shading and competition, and at maturity the crown occupies about one fifth of the stem length. The coppicing ability of black wattle is generally poor.
The flowers are predominantly insect (bee) pollinated. Copious fruiting normally occurs after 5–6 years; fruits mature in 12–14 months. The lifespan is generally 15–20 years, but some seed orchards in South Africa are nearly 30 years old and still producing seed.
In some areas, such as Hawaii and parts of South Africa, black wattle has become a noxious weed due to its aggressive colonization of denuded areas and riparian zones.

**Ecology** In its natural area of distribution, black wattle occurs in the understorey of tall open forests, in fringes of closed forests or in dense thickets on recolonized lands. Its range is from sea-level to 900 m altitude, but it mainly occurs from sea-level to about 200 m in areas with a warm subhumid to humid climate. The mean maximum temperature of the hottest month is 21–28°C, the mean minimum of the coolest month 1–7°C, with up to 40 frost days. Annual rainfall varies from (450–)625–1000(–1600) mm. Black wattle is sensitive to severe drought and to frosts of –4°C or lower. It is also very sensitive to snow damage, either snapping or bending.
In tropical countries plantations occur under wetter conditions than in the natural area of distribution. These plantations are found in highlands (1500–2500 m) with a mean annual temperature of 12–20°C, mean minimum temperature of the coolest month 2–8°C, mean maximum temperature of the hottest month 18–24°C and mean annual precipitation of 700–2000 mm. In South Africa black wattle is cultivated at 300–1000 m altitude where the climate is intermediate between that of the tree's native range and tropical conditions.
Black wattle tolerates a variety of soils, but grows best in moist, well-drained, relatively deep and light-textured soils with pH 5–6.5. It does not grow on poorly-drained, calcareous or very infertile sites.

**Propagation and planting** Black wattle is usually propagated by seed, either sown directly in the field, or in a nursery. Seed weight is low; 1 kg contains 50,000–80,000 seeds. Germination is rapid if seeds have been pretreated with very hot water (90°C). Sometimes mechanical scarification is used. Seeds retain their viability for several (to over 50) years. Vegetative propagation is not very successful but rooted cuttings, bud grafts and tissue culture have been successful in South Africa. Normally no inoculation with *Rhizobium* is needed.
Standard cultural practices can be used to raise seedlings in the nursery. Plantation sites should be well prepared by ploughing or soil ripping for establishment, but for re-establishment pitting is sufficient land preparation.
When seedlings are used in Zimbabwe, the initial stocking is about 2500 stems/ha, or a spacing of 2.7 m × 1.5 m. This is reduced to 2000 stems/ha when trees are 4 m tall and to 1500–1700 stems/

ha when they reach 7 m. Naturally regenerated stands are initially thinned into lines and then thinned to the same spacing as planted stands. When seedlings are used in South Africa, the initial stocking is about 2200 stems/ha, which is reduced to 1600 stems/ha in one or two thinning operations. The direct seeding method uses 3–5 kg/ha of seed, sown in drill lines. The large numbers of plants that grow are then rigorously thinned and initial management is more intense. Normally black wattle is not mixed with other species because its rapid growth hinders their development.

**Management** During the first year plantations should be weeded. To maintain vigorous growth, thinning should start as early as 14 months after planting, and should be repeated at least once. The degree of thinning depends on the management objectives; severe thinning favours stem diameter growth and bark production; denser stands are needed for good timber production.

Corrective pruning is necessary if the growing point of young plants has been damaged (e.g. by browsing) and multiple leaders have developed. Care should be taken to control erosion, especially when plantations are burnt (e.g. to promote regeneration). If properly managed, black wattle may help to enrich soil nitrogen as a result of rhizobial nitrogen fixation, and rehabilitate degraded lands.

**Diseases and pests** The most common disease of black wattle is black butt. The disease was first described early in the 20th Century as part of the disease complex known as gummosis. Black butt may kill the tree but it also affects the yield and quality of the bark. Associated pathogens include *Phytophthora* species and *Botryosphaeria dothidea*. In Zimbabwe, black butt occurs mainly below 1250 m altitude. A serious disease of black wattle in South Africa is wattle wilt caused by *Ceratocystis albofundus*. In the humid tropics, most damage occurs from fungal attacks of *Armillaria*, *Corticium*, *Fomes* and *Phytophthora* spp. under conditions with more than 3000 mm annual precipitation.

In its native range, black wattle is not cultivated because of serious damage by indigenous insects including the fireblight beetle *Acacicola orphana* (synonym: *Pyrgoides orphana*); sometimes severe damage may occur in Brazil, too. In most tropical countries, disease and pest attacks are generally not serious, although attacks by various insects, including defoliators (e.g. wattle bagworm, *Chaliopsis junodi*), stem-borers (e.g. *Platypus solidus*), and caterpillars (e.g. wattle looper caterpillar, *Achaea lienardi*) may occur. In Zimbabwe and South Africa, the brown wattle mirid or froghopper *Lygidolan laevigatum* is the major pest affecting mainly young plantations. It attacks the growing point of the leading shoot and upper branches causing stunted growth and a witches' broom appearance. Black wattle is also attacked by cutworms (*Agrotis* spp.) and white-grubs (Scarabaeid larvae such as *Lepidiota mashona*).

**Harvesting** Plantations for tannin bark are usually harvested after (7–)8–10(–12) years, when trees are more than 18 m tall and have a diameter of at least 15 cm. The bark is harvested by ripping it at several points near the base of the stem with a hatchet or short iron bar flattened at the end; the loosened strips of bark are pulled from the stem. After stripping, the bark is cut to bundle length; in Zimbabwe this is about 1.2 m. Stripping is easiest during periods of active growth. In Zimbabwe, timber is windrowed for later recovery against pole orders, but much of it cannot be sold and is burnt during subsequent land preparation.

**Yield** In South Africa typical yields of fertilized plantations are 15–25 $m^3$/ha per year of wood and 1.5–2 t/ha of dry bark. In tropical regions, and with good management, yields range between 25 $m^3$/ha and 35 $m^3$/ha per year of wood and from 0.9–2 t/ha of dry bark. At the best sites 60–65% of the yield consists of first grade bark from stems of at least 15 cm diameter, on poorer sites the proportion is only 40–50%.

**Handling after harvest** The harvested bark is either transported immediately or dried locally first. In South Africa, all bark is delivered fresh to the mill. In Zimbabwe most bark is processed fresh, but bark harvested after the milling season is dried for processing during the next season. When dried bark is used, drying should be done in partial shade; the inner bark darkens if exposed to direct sunlight. The bark discolours if it is re-wetted after drying. To obtain good bark quality, kiln drying is practised sometimes. In Indonesia trials have been done on portable charcoal-burning drying kilns in which the bark can be completely dried in about 60 hours. During drying the bark curls inwards; these 'sticks' are bundled for transport. During processing, the bark may either be extracted or prepared for marketing as dry bark. Fresh bark is preferred for extraction. Dry bark is graded according to thickness, maturity, lightness of colour, absence of corkiness and freedom from mould. It is mar-

keted as chopped bark, ground bark or sometimes as dust, in pressed bales or in bags.

**Genetic resources** It is thought that the seed used for black wattle plantations outside Australia originated from a limited part of the natural range. Germplasm collections exist at the CSIRO Division of Forest Research, Canberra, Australia and at the Institute for Commercial Forestry Research (ICFR), formerly the Wattle Research Institute (WRI), Pietermaritzburg, South Africa. Some provenance testing has been done, e.g. by the ICFR and in China, but further studies are needed.

**Breeding** Major breeding objectives are enhanced vigour, better bark quality and stem form, and resistance to pests and diseases. The emphasis in the breeding programme in South Africa has shifted from improved bark yield and quality to improved timber yield and quality with acceptable bark yield and quality.

**Prospects** Due to substitution of plastics for leather and the subsequent decline in the importance of tannin since the 1960s, black wattle cultivation has decreased in importance. However, it is still a potential substitute for synthetic tannins, which are widely used in the tanning industry and damage the environment. More recently the demand for black wattle timber in South Africa, and for export, has led to the conversion of some eucalypt plantations to black wattle. Woodlots of black wattle are being planted by rural farmers in South Africa for fuelwood and as a source of building material. Black wattle is important because of its multipurpose functions and its adaptability to a wide range of ecological conditions, including degraded sites. Special consideration should be given to using black wattle for soil rehabilitation in local land use systems.

**Major references** 5431, 5432, 5433, 5434, 5435, 5436, 5437, 5438, 5441, 5442

**Other references** 5427, 5428, 5429, 5430, 5439, 5440, 5443, 5444, 5445, 5446, 5447, 5448

**Sources of illustration** 3785

**Authors** R.W. Dunlop

## ACACIA SENEGAL (L.) Willd.

**Protologue** Sp. pl. 4(2): 1077 (1806).

**Family** Mimosaceae (Leguminosae - Mimosoideae)

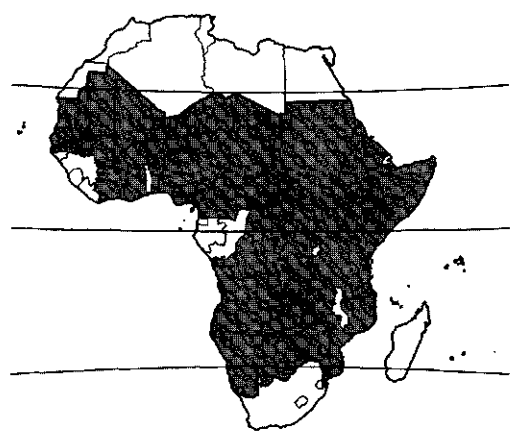
**Chromosome number** $2n = 26$

**Synonyms** *Mimosa senegal* L. (1753), *Senegalia senegal* (L.) Britton (1930).

**Vernacular names** Gum tree, gum arabic tree, three-thorned acacia (En). Gommier, gommier blanc (Fr). Aiti, kikwata, mgunga (Sw).

**Origin and geographic distribution** *Acacia senegal* is widely distributed in the drier parts of tropical Africa, from Senegal and Mauritania in the west to Eritrea and Ethiopia in the north-east and to South Africa in the south. Of the 4 recognized varieties var. *senegal* is the most widespread and is found throughout the area of distribution of *Acacia senegal* except along the west coast of central and southern Africa; outside Africa it occurs in Oman, Pakistan and India and has been introduced into Egypt, Australia, Puerto Rico and the Virgin Islands. This variety is the major source of gum arabic. Var. *kerensis* Schweinf. occurs in Ethiopia, Somalia, Uganda, Kenya and Tanzania; var. *leiorhachis* Brenan throughout eastern Africa from Ethiopia to South Africa; var. *rostrata* (Sim) Brenan in the same area and in Namibia and Angola, and possibly also in Oman.

**Uses** Gum arabic is the exudate formed in the bark of *Acacia senegal*, *Acacia seyal* Delile and a few related species. In Sudan and sometimes in international trade, a distinction is made between 'gum hashab' from *Acacia senegal* and 'gum talha' from *Acacia seyal*. Gum arabic is easily soluble in water and forms solutions over a wide range of concentrations. It has highly valued emulsifying, stabilising, thickening and suspending properties and does not become highly viscous. The food industry uses 60–75% of the world production. In confectionery, gum arabic is used to prevent crystallisation of sugar, as an emulsifier, and as a glaze or topping in bakery products; in soft drinks and alcoholic drinks it is used either as a



*Acacia senegal – wild and planted.*

vehicle for flavouring or as a stabiliser or clouding agent; in frozen dairy products gum arabic is used for encapsulating flavours such as citrus oils. Its pharmaceutical use has decreased, but it is still used as a suspending or emulsifying agent and in tablet manufacture, where it functions as a binding agent or as a coating prior to sugar coating. Gum arabic is used in the printing industry for coating offset lithographic plates to prevent oxidation, to increase their hydrophilic properties and to make them repellent to ink. It is also a base for photosensitive chemicals. In ceramics, gum arabic helps to strengthen the clay. Other technical applications include pyrotechnics and ink manufacturing. In textiles, paints, paper size and adhesives (including the traditional office glue and postage stamps) its use has decreased to very low levels in recent years. Gum arabic is used locally in special dishes and as chewing gum; it has medicinal applications for both humans and livestock, e.g. to treat skin diseases and inflammation.

*Acacia senegal* is a multipurpose tree. The foliage and pods are an important fodder source for camels and goats. Seed may be dried and conserved for human consumption mainly as an emergency food. The wood is used for small-scale construction purposes and agricultural implements; it yields a fuelwood of good quality, that can be made into good charcoal. The thorny branches are often used to make 'dead fences' to enclose livestock or protect agricultural fields. Being a very drought-resistant tree, it is planted for sand dune fixation, windbreaks and shelter belts in arid regions. Bark, leaves and gum are used as an astringent to treat colds, ophthalmia, diarrhoea and haemorrhages. The flowers are a source of honey. Cordage is made from the roots, either directly or after beating to extract the fibres; its strength makes it suitable for well ropes and fishing nets. The seed contains a fat which is used both in medicine and for soap making.

**Production and international trade** The term 'gum arabic' was coined by European traders, who imported it from Arabian ports such as Jeddah and Alexandria. Sudan dominates the world market, accounting for about 80% of the volume produced. Around 1970 annual trade amounted to 70,000 t, but 2 serious droughts brought trade down to 20,000–24,000 t in 1992. During the periods of shortage, many companies invested in alternative manufacturing equipment using other hydrocolloids, resulting in an irreversible loss of market share for gum arabic. From 1988 to 1994, annual exports from Sudan averaged nearly 20,000 t of 'gum hashab' whereas Nigeria exported over 4800 t of gum arabic during the same period. Part of the production of Sudan is illicitly exported via other countries. The European Union is by far the largest market for gum arabic and imported an average of 28,000 t/year for the period 1988–1993. The price per t (ex Port Sudan) from 1980 to 1992 fluctuated as a result of years of shortage and years of surpluses from US$ 1500 (1980) to US$ 5000 (1983–1984) and US$ 2300 (1988–1991) to US$ 7000–9000 in 1992. The 1994–1995 prices (FOB, Port Sudan) of the best quality 'gum hashab' were US$ 5000/t. Gum arabic from Sudan is traded in several quality classes; the most important ones (with their indicative 1994–1995 prices FOB, Port Sudan) are: 'hand-picked selected' (US$ 4850), 'cleaned and sifted' (US$ 4200), 'kibbled' (US$ 5000), 'dust' (US$ 2760). In 1994, the price of Nigerian gum arabic Grade 1 was US$ 3500/t. The United States imports mainly processed gum arabic from Europe.

**Properties** Gum arabic is a pale to orange-brown solid, which breaks with a glassy fracture. The best grades have the shape of whole, round tears, orange-brown in colour and with a matt surface texture; after processing to the broken or 'kibbled' state the pieces are much paler and have a glassy appearance. Unlike many other vegetable gums, gum arabic dissolves very well in water (up to 50%). The solution is colourless and free of taste and does not readily interact with other chemical compounds. Chemically, gum arabic is a slightly acidic complex composite of glycoproteins and polysaccharides and their calcium, magnesium and potassium salts. The main polysaccharide is arabic acid, a branched polysaccharide with a (1,3)-linked D-galactose backbone with (1,6)-linked ramified branches composed of L-arabinose, L-rhamnose and D-glucuronic acids. The proteins are characterized as hydroxyproline-rich arabinogalactan proteins. Commercial samples of gum arabic showed the following composition: arabinose 24–29%, galactose 32–41%, rhamnose 12–18%, uronic acid 14–17% and protein about 2%. The molecular weight is 47,000–3,000,000, representing a number of basic monomeric sugars of 290–18,500. In human nutrition, gum arabic has less than 1 cal/g.

As gums similar to gum arabic are obtained from several acacias and even from non-*Acacia* species, official specifications to identify true gum arabic are important. However, these specifications have

a confusing history in which the term 'gum arabic' is sometimes used exclusively for gum from *Acacia senegal*, and sometimes for gums from several *Acacia* species. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) indicated in its Compendium on food additive specifications - Addendum 7 (1999) that no distinction is made between gum from *Acacia senegal* and *Acacia seyal*; gum from other *Acacia* species is not admitted. Some of the further specifications are: 1 g should dissolve in 2 ml water and be acidic in a litmus test, but be insoluble in ethanol; mannose, xylose and galacturonic acid should be absent; the optical rotation of an aqueous solution of gum from *Acacia senegal* should be laevorotatory, that from *Acacia seyal* dextrorotatory; the loss on drying should be not more than 15% for granular material and not more than 10% for spray-dried material; gum arabic should be free of starch and dextrin, tannins, *Salmonella* spp. and *Escherichia coli*.

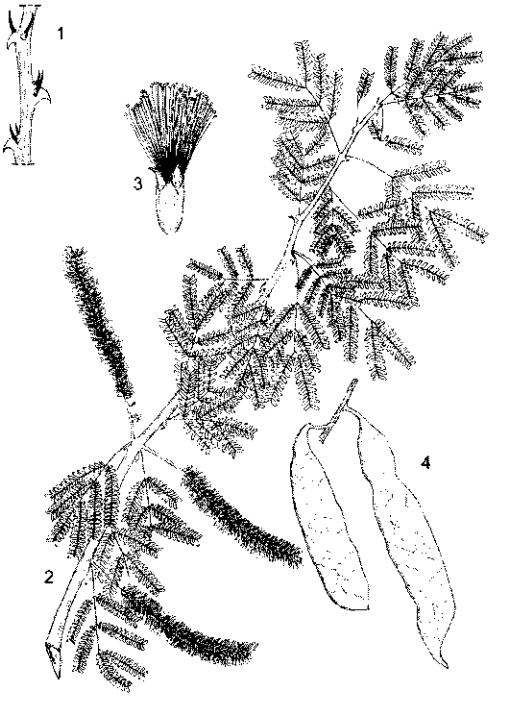
Export consignments from Sudan receive a certificate giving the analytical data such as moisture content, acid-insoluble matter and optical rotation. Commercial gum arabic samples have a moisture content of 9–14%, an optical rotation of $([\alpha]^{20}_{D})$ –26° to –34° and a nitrogen content of 0.27–0.39% . Gum of *Acacia seyal* is dextrorotary (+54°) and can as such be distinguished from *Acacia senegal* gum. In Europe, gum arabic is admitted as food additive under No E414; in the United States it has FDA GRAS (generally recognized as safe) status.

'Gum hashab' from Sudan is the highest quality and sets the standard. Within Sudan, gum arabic from the Kordofan region has the highest reputation, and traders and end-users in importing countries often refer to 'Kordofan gum' when indicating their preferences. Nigerian gum arabic is of very variable quality. A major problem is the inconsistent and heterogenous nature of consignments: gum of varying degrees of cleanliness and colour is present, which reflects the less rigorous methods of harvesting and post-harvest handling when compared to 'gum hasbab' from Sudan. Mixing gum from different *Acacia* spp. adversely affects the quality. Officially, Nigerian gum arabic Grade 1 is pure gum of *Acacia senegal*, Grade 2 may include gum from *Acacia seyal* and other *Acacia* species, while Grade 3 may contain gum from species other than *Acacia*.

The nutritive value for livestock of young shoots, green pods and seeds respectively is as follows: crude protein 20%, 22% and 39%, crude fibre 28%, 39% and 21% and nitrogen-free extract 42%, 31% and 26%. The leaves contain 10–13%, the pods 15% digestible protein. The wood is dark to almost black, heavy and hard and can be polished well. It is termite resistant. The energy value of the wood is about 13,400 kJ/kg.

**Adulterations and substitutes** Gums from other acacias, and sometimes from *Albizia* and *Combretum*, are also marketed as gum arabic. Although regulations for the admission of gum arabic no longer distinguish between gums from *Acacia senegal* and *Acacia seyal*, and although the gum of *Acacia seyal* is most often marketed as gum arabic, its properties are inferior to those of the gum from *Acacia senegal*. In exports from Sudan, the distinction is clearly made: gum from *Acacia senegal* is marketed as 'gum hashab', while gum from *Acacia seyal* is sold under the name 'gum talha'. In Zimbabwe, gum from *Acacia karroo* is locally traded as gum arabic. Synthetic substitutes for gum arabic are the 'modified starches', such as xanthan and gellan, which increasingly replace gum arabic as food hydrocolloids.

**Description** Armed, deciduous shrub or small to medium-sized tree up to 15 m tall; bark yellowish-brown to purplish-black, rough or smooth,




*Acacia senegal – 1, part of branch with prickles; 2, flowering branch; 3, flower; 4, fruits. Redrawn and adapted by M.M. Spitteler.*

papery and peeling off in strips or not, deeply fissured and blackish on old trees; crown slightly rounded or flattened and somewhat spreading, or slender and spindly with irregular virgate branches; branchlets glabrous to densely pubescent, with prickles just below the nodes, either in 3s with the central one hooked downwards and the lateral ones curved upwards, or with laterals absent, young prickles reddish, later blackish. Leaves alternate, bipinnate; stipules minute or absent; petiole, rhachis and rhachillae sparingly to densely clothed with spreading hairs, rarely glabrous; pinnae in (2–)3–8(–12) pairs; leaflets in 7–25 pairs, linear to elliptical-oblong, 1–5(–9) mm × 0.5–2(–3) mm, sparingly appressed-pubescent on both surfaces or glabrous. Inflorescence an axillary spike up to 12 cm long, axis densely pubescent or glabrous. Flowers bisexual, white or cream in colour; calyx 2–3(–3.5) mm long, glabrous to somewhat pubescent; corolla 3–4 mm long; stamens numerous, up to 7 mm long; ovary superior, shortly stalked, glabrous. Fruit an oblong pod, (2–)4–19 cm × 1–3.5 cm, rounded to acuminate apically, venose, sparsely to densely appressed-pubescent or puberulous, yellowish- or greyish-brown to brown, dehiscent, up to 7-seeded. Seeds subcircular-lenticular, 8–12 mm in diameter, areole 2.5–6 mm × 2.5–5 mm, impressed, horseshoe-shaped.

**Other botanical information** *Acacia senegal* is classified in the subgenus *Aculeiferum*, which is based chiefly on characters of seed and seedlings, on the absence of stipular spines (but prickles present) and pollen characters. Subgenus *Aculeiferum* accommodates all African *Acacia* species lacking spinescent stipules. Generally 4 varieties are distinguished in *Acacia senegal*: var. *senegal*, var. *kerensis* Schweinf., var. *leiorhachis* Brenan and var. *rostrata* (Sim) Brenan. It is doubtful whether var. *kerensis* is a good taxon as it only represents the shrubby growth form of *Acacia senegal*; all shrubby specimens in northeast Africa are referred to as var. *kerensis*. Var. *senegal* can be distinguished from the other 3 varieties by the following combination of characters: tree with a single central stem and a usually dense flat-topped crown, bark without any papery peel, rough, peduncle pubescent (very rarely glabrous) and pods usually rounded to somewhat pointed, but never rostrate or acuminate at the apex. None of the varieties *kerensis*, *leiorhachis* or *rostrata* appear to produce much gum in their native range.

**Anatomy** Gum arabic is formed in cysts in the inner bark of the branches and not in the wood. The gum cysts are formed first in the parenchyma of the phloem. In case of wounding, the gum is transported to the wounded site via new channels formed by lysis of cells.

The following wood description is based on South African samples of the varieties *leiorhachis* and *rostrata*.

– Macroscopic characters:

Sapwood pale to creamy yellow, heartwood pale to dark brown.

– Microscopic characters:

Growth rings consisting of flattened marginal parenchyma or thick-walled fibres. Vessels solitary, in pairs or radial groups, 70–200 µm; perforation plates simple; intervessel pits alternate, vestured, vessel-ray pits similar to intervessel pits. Fibres with simple pits. Axial parenchyma confluent (var. *leiorhachis*) or banded (var. *rostrata*). Rays 1–5-seriate, homogenous, average height 270 µm (var. *leiorhachis*) to 420 µm (var. *rostrata*). Prismatic crystals in chambered axial parenchyma cells.

**Growth and development** Under favourable conditions *Acacia senegal* can start flowering when 3 years old. It flowers on branches formed during the previous rainy season. Flowers open from the base to the tip of the inflorescence in 24 hours. They show weak protogyny, with the styles protruding above the stamens in open flowers. In Sudan, flowering is in June–July, in western Africa the flowering peak occurs around July–September and fruits are mature between the end of November and early February. In South Africa, flowering is in December–January(–April) and fruits are ripe in October. Pollination is presumably by insects. Good seed years are relatively infrequent. In the first growing season the taproot can grow up to 4 m long. Later a fairly dense lateral root system develops which can reach up to 13 m from the taproot and is able to collect rain water from an area of up to 500 $m^2$.

In southern Ethiopia, 5-year-old trees have a wood volume increment per year and per ha of 5.4–5.9 $m^3$, a mean height of 5.0 m and a mean diameter at breast height of 7.4–7.7 cm on sites at 1580–1650 m altitude which receive an annual rainfall of 625–690 mm. Generally, wood production of natural stands is estimated at 4–7 $m^3$ per ha per year. In gum plantations wood production is only 0.5–1 $m^3$ per ha per year.

The relationship between the degree of vigour of trees and their ability to exude gum and the contingent role of pathogenic organisms in the induction of gummosis are still not known. A negative correlation between soil water availabil-

ity and relative air humidity on the one hand and gum yield on the other has been observed in Senegal, but this fact needs confirmation from other observations.

Nodulation has been observed in *Acacia senegal* but the amount of nitrogen fixation is fairly low compared to other *Acacia* species. Mycorrhizal associations have been observed in the form of vesicular-arbuscular mycorrhizae. South Africa and Australia have policies against further introduction of *Acacia senegal* var. *rostrata* and var. *leiorhachis* as both varieties may become noxious weeds there.

**Ecology** *Acacia senegal* grows in tropical and sub-tropical, arid and semi-arid regions and is very drought resistant. Trees survive in the most adverse conditions, subject to hot winds and sandstorms on the poorest soils of rock and sand. *Acacia senegal* occurs naturally in areas with an annual rainfall of (100–)200–400(–800) mm with 7–11 dry months/year. However, in some highland sites in Rwanda and Kenya it may receive as much as 1000 mm of rain. Average annual temperatures commonly vary from 25–30°C, although it can withstand mean maximum temperatures of 45°C. The mean maximum temperature in the hottest month is 30–41°C, the mean minimum temperature in the coldest month is 4–15°C. Over most of its natural range *Acacia senegal* is sensitive to frost, although in Asia it occurs in areas with minimum temperatures as low as –2.5°C to –5°C. The altitude range of *Acacia senegal* is 0–2000 m. It is associated with a variety of vegetation types ranging from semi-desert grassland to *Anogeissus* woodland. Sandy soils are preferred, particularly those of fossil dunes in the Sahel, but it will also grow on loamy sand, on rocky hill slopes and even on clay plains, provided they are well drained and rainfall is at least around 600 mm/year, compensating for the lower available soil moisture. It will not grow on mineral soils or strongly leached ferrous soils. A coarse texture is preferred. There is no correlation of soil organic matter content with abundance of *Acacia senegal*. Free drainage is essential and waterlogging is not tolerated at all. The pH of the soil may range from slightly acid to moderately alkaline.

**Propagation and planting** *Acacia senegal* var. *senegal* can be propagated by seed and by tissue culture. One kg contains 7000–19,000 seeds. The hard-coated seeds are orthodox and remain viable for up to 7 years when stored under cool and dry conditions. Fresh seed with a soft seed coat can be sown immediately without pretreatment, but pretreatment is required for seed which has been stored for several months. Treatment with concentrated sulphuric acid for 3–15 minutes or immersion in boiling water for 5 seconds is satisfactory. Older seed may be treated with concentrated sulphuric acid for 40 minutes or soaked in water for 12–24 hours. Polythene bags 30 cm high and 6 cm in diameter with light and moist soil are used for sowing. No compost is applied to avoid overheating by fermentation. Per bag 2–4 seeds are sown 1 cm deep. One kg of seed will produce 4000–6000 seedlings. After 4–6 weeks the seedlings are thinned to 1 per pot. Removed seedlings cannot withstand transplanting to other bags. After 14–18 weeks, seedlings attain a height of 30 cm and can be planted out in the field. Planting is done in pits of 30 cm × 30 cm × 30 cm spaced at 4 m × 4 m. For direct sowing, 5–8 seeds are sown in similar pits at the same spacing. Mechanised seeding has been successful on the clay plains in Sudan. In compact soils larger planting holes of up to 60 cm × 60 cm × 60 cm may be required, or subsoiling should be done up to 60–70 cm deep. The latter method is often too expensive. Application of 150 g of NPK fertiliser per planting hole not only assures faster growth in the 1st year but also increases drought resistance of the planted seedlings. Weeding is essential after planting, 2–3 times during the first year and for another 2 growing seasons. The young plants need protection from livestock for the first 3 years until they have grown out of their reach. Planting at a wide spacing of 10 m × 10 m or direct sowing allows for interplanting with annual crops such as millet, beans or groundnuts. *In vitro* micropropagation of *Acacia senegal* has been successful, but it is probably only economic to multiply high-yielding mother trees. Natural regeneration is very unpredictable due to the irregularity of rains and the frequent attack of the seeds by insects and rodents. However, regrowth occurs often from coppice.

**Management** In Sudan, gum trees were traditionally grown in a controlled bush fallow system with a 20–25 year rotation; 4–5 years of cropping was alternated with a fallow period with gum trees for 15–20 years. The gum trees needed 5 years to become established and could be tapped for the remaining fallow period. When gum production declined, all gum trees were cut at 1.5 m height or sometimes killed by fire. Cutting at ground level will also kill the tree. After the rotation period with crops, gum trees were either regenerated or were sown at the same time as the last crops. Animals were allowed to graze during

the fallow period after tapping the gum trees and crop harvesting. The tree density in a productive stand used to be 500–2000 trees/ha. Unfortunately, this fallow system has collapsed due to the combination of the Sahel drought, especially the drought from 1979 to 1986, pressure for cultivated land, low prices received by tappers and the high prices obtained for fuelwood. Only in southern parts of Kordofan province have farmers maintained their gum gardens due to better revenues which were obtained by smuggling gum arabic to Chad. Government-owned plantations, which were left untapped during the drought to reduce stress on the trees, grew vigorously again after the rains returned. By 1996 the Sudanese Forest Service had established 12,500 ha of new gum tree plantations inside forest reserves to act as buffer plantations. These are now rented out to gum tappers on a sharecropping basis.

**Diseases and pests** *Acacia senegal* trees are mildly susceptible to root knot nematodes. Locusts (*Acridium melanorhodon*) can defoliate vast areas overnight, but trees normally recover. The buffalo treehopper (*Stictocephala bubalus*) destroys 15–85% of fallen seed.

**Harvesting** In Sudan, tapping usually starts when trees are 4–5 years old and begins when they are starting to shed their leaves or when the grass beneath them starts to dry out, usually about the end of October or beginning of November. The start of tapping coincides with the tree's largest accumulation of carbohydrate reserves from the previous rainy season. All main branches are tapped, but the main stem is not tapped, as the bark would soon become too thick and fibrous. In Sudan a special tool with a metal head known as a 'sunki' is used. A tangential cut is made penetrating just below the bark; then a longitudinal strip of bark of 2–3 cm wide and 1 m long is pulled off from the wood. Damage to the wood should be minimal. Several branches are treated in a similar manner in one tapping round. In subsequent years, other branches, or the reverse side of the previously treated branches, are tapped. After the superficial injury, gum exudes intermittently, forming nodules with a hard but slightly elastic skin. As more gum exudes the outer skin expands or cracks and the nodule grows in size to 3–5 cm in diameter. After 4–6 weeks the skin becomes too hard to expand any further, the nodule ceases to grow and is ready for picking. Collections are made from the same trees at intervals of approximately 2 weeks until February. Tapping wounds are overgrown by the end of the next rainy season. In Sudan, tapping is the work of men; women are responsible for harvesting, cleaning, storage and transport of the produce. The tears of gum are preferably picked by hand from the branches, which implies that tapping should only be done from the lower branches. When the tears are knocked off, they pick up dirt which seriously impairs the quality. The collected tears are carried in open baskets; the use of plastic bags increases the risk of moisture retention and mould formation. A tapper may tap up to 100 trees per day, covering up to 30 ha per season. During the rainy season, gum exudation does not occur, while some trees that are tapped do not produce gum at all. Older trees produce a darker gum containing more tannins from the bark. In Mali, harvesting periods are December–January and May–June, the latter being the more productive one.

Natural exudation, particularly known from northern Kenya where trees are not tapped, is generally provoked by wounding, for example, from particles carried by the wind, drought, browsing animals, insects or parasitic plants.

**Yield** Yields of gum arabic from individual trees are very variable and few reliable data are available. A yield of 250 g/tree per season is generally cited as average, but individual trees may yield several kg. A figure of 100 g/tree is reported for Mauritania. Yields from cultivated trees are said to increase up to the age of 15 years, when they level off and then begin to decline after 20 years. In Mali, the best yields from *Acacia senegal* are said to be produced between ages 7 and 15 years.

**Handling after harvest** In Sudan, the minimum guaranteed gum price is fixed by the government; the price is lower in years when buffer stocks accumulate to discourage maximum production, whereas in years of shortage the opposite applies. Sudanese merchants buy the gum competitively at auction, and are obliged to pay the supplier immediately after the auction. The Gum Arabic Company will buy at the official base price any gum that remains unsold. The gum is then cleaned and graded into the following grades: Hand-Picked Selected (HPS), Cleaned and Sifted (CAS), Cleaned Natural, Red Gum, Gum Siftings, and Gum Dust. Cleaning and grading involves sorting the gum into whole tears and smaller pieces, while separating any dark gum and removing pieces of bark and other foreign matter. All gum for export is subsequently purchased by the Gum Arabic Company, cleaned again and packed for export in jute bags. A 40% export tax is levied by the government. This

system, introduced in 1967–1968 to ensure the quality of Sudanese production, is being abused by smuggling of gum to neighbouring countries to avoid export duty.

Nigerian gum arabic is sorted into 3 grades; Grade 1 is gum produced from *Acacia senegal*, Grade 2 is gum from other *Acacia* species, and Grade 3 is much darker and very mixed in quality and may consist of gum from species other than *Acacia* (e.g. *Albizia* and *Combretum*).

From the 1993/1994 production season, Sudan began producing kibbled gum; 2500 t were produced. Previously, all kibbling was done in consumer countries. Kibbling entails passing whole tears or large lumps of gum through a hammer mill and screening it to produce smaller granules of more uniform size. These pieces are more easily dissolved in water. Powdered gum may be produced from kibbled gum but it may also be produced by spray-drying. The gum is dissolved in water, filtered and/or centrifuged to remove impurities and the solution, after pasteurization to remove microbial contamination, is sprayed into a stream of hot air to promote evaporation of water. Although spray-drying adds around US$ 1000/t to the price of gum arabic, it is preferred by most food processing manufacturers, who do not want to stock raw gum arabic, of which the microbiological quality may not be good.

**Genetic resources** Isozyme studies indicate that West African provenances of *Acacia senegal* var. *senegal* show little variation. Although small collections of germplasm exist, they do not cover the full geographic and genetic variability, as collection activities have concentrated on high gum-yielding provenances of *Acacia senegal* var. *senegal*.

**Breeding** The relationship between the degree of vigour of trees and their ability to exude gum and the contingent role of pathogenic organisms in the induction of gummosis are still not known. Before selection of high-yielding strains can be made, more physiological and anatomical information is needed on the mode of gum production.

**Prospects** The lost market share of gum arabic due to droughts and high prices in the 1980s is unlikely to be regained as industries consuming gum arabic have changed to other hydrocolloids, mainly modified starches, in their production processes. However, the 1992 trade of 20,000–24,000 t is still considerable. Increased production and consequent favourable prices, and the marketing asset of a natural product, may lead to better prospects in the future.

**Major references** 2023, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049

**Other references** 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2050, 2051, 2052

**Sources of illustration** 2053 (part of branch with prickles), 2054 (flowering branch, flower, fruits)

**Authors** E. Boer

## AFRAMOMUM CORRORIMA (Braun)

P.C.M.Jansen

**Protologue** Spices, condiments and med. pl. Ethiopia (Agric. Res. Rep. 906, Belmontia 12): 10 (1981).

**Family** Zingiberaceae

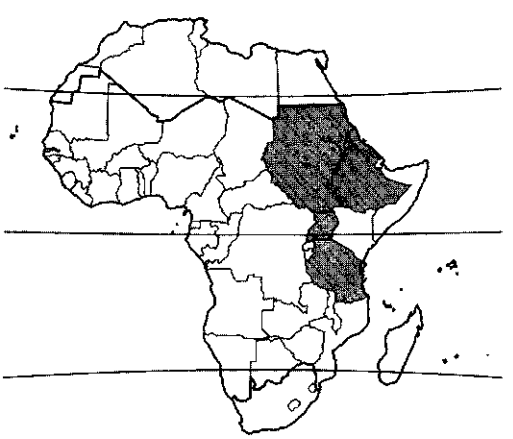
**Chromosome number** $2n$ = unknown

**Synonyms** *Amomum corrorima* Braun (1848), *Amomum korarima* J.Pereira (1850), *Aframomum korarima* (J.Pereira) K.Schum. ex Engl. (1908), *Aframomum usambarense* Lock (1976).

**Vernacular names** Korarima, Ethiopian cardamom, false cardamom (En). Korarima, cardamome d'Ethiopie, poivre d'Ethiopie (Fr).

**Origin and geographic distribution** *Aframomum corrorima* is widely distributed in western Ethiopia (Provinces of Kefa, Sidamo, Illubabor and Wollega), Sudan (south-western, Aloma Plateau), Uganda (western) and Tanzania (Usambara Mountains). In Ethiopia it is also occasionally cultivated outside its natural area (around Lake Tana and Gelemso) and it is cultivated in Eritrea.

**Uses** The use of korarima is only known from Ethiopia and Eritrea. The seeds (usually dried, sometimes fresh) are used to flavour all kinds of



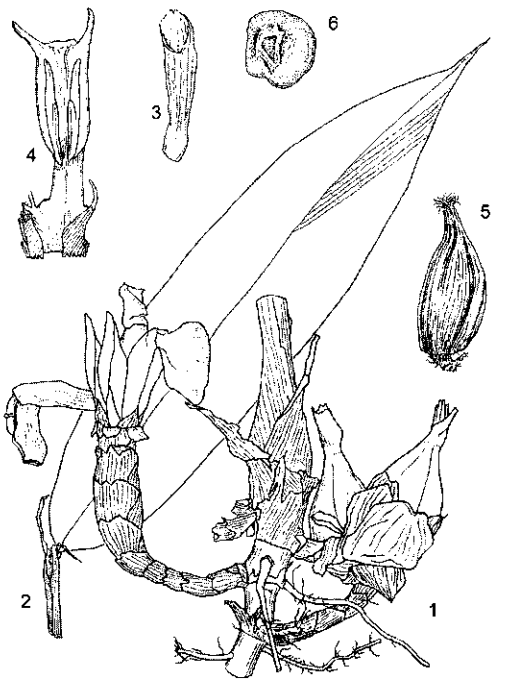
*Aframomum corrorima – wild and planted.*

sauces, for which they are ground and usually mixed with other spices; occasionally they are also used to flavour coffee, tea, bread and butter. In Ethiopia, the seeds are used medicinally as a tonic, carminative and purgative. The arilloid flesh around the seed is edible. Strings of fruits are sometimes used as an ornament, or as rosaries (by the Arabs), and in the past the fruits have been used as money in Ethiopia.

**Production and international trade** Although no statistics are available, the amount of korarima fruits (the seeds are sold per fruit) offered for sale in Ethiopia is considerable. Korarima is present at every market, and is sold for a high price compared to other spices. Some korarima is exported from Ethiopia to markets in Sudan, Egypt, the Arabian peninsula, Iran and India. Export to Europe and the United States is very small, mainly due to the product often being of poor quality.

**Properties** Korarima seed has a mild, sweet flavour and is less peppery or pungent than seed of *Aframomum melegueta* K.Schum. (grain of paradise). The seeds contain essential oil which has a typical odour and is sometimes called 'nutmeg-cardamom'. After distillation of dried comminuted fruits, 3–3.5% of a pale yellow volatile oil with a flat cineolic odour can be obtained, in which the following compounds have been found (all monoterpenes, approximate amount of the major ones): 1,8-cineol 32–35%, limonene 7–14%, β-pinene 4–7%, sabinene 7–9%, terpinen-4-ol 3–5%, geraniol 5%, P-cymene 4%, α-pinene, α-terpineol and γ-terpinene 3% each. Sesquiterpenes were identified in another analysis; the total was dominated by about 75% monoterpenes including 1,8-cineol (38%) and terpinyl acetate (11%), and 17% sesquiterpenes including nerolidol (11–14%), β-caryophyllene (2%) and caryophyllene oxide (1%).

**Description** Perennial, rhizomatous, aromatic herb; leafy stems 1–2 m tall; rhizome subterete, up to 1 cm in diameter, profusely branched, red-brown, covered with thin, subovate scales up to 6 cm × 4 cm and bearing thin, fibrous, pale brown roots; stem unbranched, mainly formed by the leaf sheaths, subterete, up to 1 cm in diameter but at base usually thickened up to 3 cm diameter. Leaves alternate, distichous, simple; sheaths covering each other, yellow-green, with prominent veins and scarious, ciliate margins; ligule deeply bilobed, thin, ciliate, lobes acute, up to 3 cm long; petiole 4–10 mm long, deeply grooved above; blade elliptical to oblong, 10–30 cm × 2.5–6 cm, obliquely obtuse at base, cuspidate at apex,




*Aframomum corrorima – 1, part of rhizome with flowers and fruits; 2, leaf; 3, calyx; 4, anther; 5, dried fruit; 6, dried seed.*
*Redrawn and adapted by M.M. Spitteler.*

margin entire, glossy dark green above, paler green and often a bit reddish below, lateral veins fine, pinnately arranged but parallel, making a very sharp angle with the midrib, 4–9 per 5 mm above, 12–16 per 5 mm below. Inflorescence a shortly stalked head arising from the rhizome near the base of a leafy stem, sometimes situated at the end of a rhizomatous runner, up to 5-flowered; peduncle up to 7 cm long, covered by imbricate, purplish-brown, subovate scales 2.5 cm × 1.5 cm; head covered with imbricate, purplish-brown, ovate to square bracts up to 4.5 cm in diameter; each flower surrounded by a scarious, suboblong bract up to 6 cm × 2 cm, bidentate, ciliate. Flowers bisexual, zygomorphic; calyx spathaceous, up to 4.5 cm × 1 cm; corolla tubular, 3-lobed at apex, white to pale violet, tube up to 4.5 cm long, densely woolly in upper 2 cm, lateral lobes ovate-oblong, up to 4 cm × 2 cm, dorsal lobe up to 4 cm × 3 cm, labellum obovate in outline, with a half-tubular fleshy claw up to 3 cm × 1.5 cm and a subovate to orbicular lobe up to 3 cm × 3.5 cm, thin, slightly notched, yellow at throat inside; fertile stamen 1, filament fleshy, slightly rounded, 6 mm × 5 mm, connectivum fleshy, at

apex with 2 lateral horns 4 mm long, thecae 2, narrowly ellipsoid, about 11 mm × 1 mm; ovary inferior, 3-locular, style thin, terete, up to 5 cm long, stigma funnel-shaped, 2 mm wide, ciliate, top of ovary provided with 2 (sometimes more) lobed, fleshy outgrowths (probably nectaries), partly clasping the style. Fruit an indehiscent, subconical berry up to 6 cm × 3.5 cm, usually showing 3 longitudinal furrows but sometimes more, shiny green when immature, turning bright red at maturity, with 3 cells containing 45–65 seeds each. Seeds subglobose in outline but usually somewhat angular, 2–5 mm in diameter, testa finely lined, glossy brown, hilum circular, whitish, aril thin, a bit fleshy, completely covering the seed.

**Other botanical information** The genus *Aframomum* comprises about 50 species and is widely distributed in the wetter parts of tropical Africa. It is closely related to *Amomum* from tropical Asia and was formerly included in it. The differences between the 2 genera are not constant and it is possible that in the future the 2 genera will be united again.

*Aframomum zambesiacum* (Baker) K.Schum. occurs in similar habitats as *Aframomum corrorima*. The seeds of the former species, however, are not used, and in Ethiopia it is called 'monkey's korarima'. Two major differences with the real korarima are that its leaves are less aromatic upon crushing, and its inflorescences bear 25–50 flowers (korarima only up to 5).

**Growth and development** In Ethiopia, korarima flowers between January and September. Fruits mature about 2–3 months after flowering. In Kefa Province of Ethiopia the main flowering period is June–July, with fruiting in September–October. Most probably the flowers are open for only one day. The position of the stigma in the flower, below or against the base of the thecae of the anthers, hints at self-pollination, but there is neither observational nor experimental evidence. The presence of large nectaries at the top of the ovary make insect visits probable. In many other *Aframomum* species, the stigma is situated at the top of the anther thecae and cross-pollination caused by insects is the rule, although the plants are self-fertile too. Animals such as monkeys eat the aril around the seeds and certainly contribute to natural dispersal of the seeds.

**Ecology** Korarima grows naturally at (1350–) 1700–2000 m altitude in slightly shaded, more or less open sites in higher altitude rain forest. Annual rainfall varies from 1300 mm to more than 2000 mm; there is no distinct dry season but usually most rain falls in June–August (50–60%). The annual average temperature is about 20°C. In Ethiopia, korarima grows in almost the same habitats as wild coffee species (*Coffea*).

**Propagation and planting** Korarima can be propagated by seed but planting rhizome parts is probably easier and quicker.

**Management** No information is available about cultivation methods of korarima. Possibly the method of cultivation is similar to that for the West African *Aframomum melegueta* K.Schum. (grain of paradise, melegueta pepper). The seeds of the latter species are sown in the rainy season in the shade of other crops and transplanted the next rainy season to more even spacing. Plants start producing fruits 3 years after sowing and may continue to fruit during the next 4 years. Perhaps people influence the wild population of korarima by some kind of protection and aid wider dispersal by planting.

**Diseases and pests** No serious diseases or pests are known for korarima. The rust *Puccinia aframomi* has been observed on korarima leaves in Ethiopia.

**Harvesting** Fruits are mostly harvested from the wild. The seeds are best harvested when the fruits are red and mature.

**Yield** The yield can be as much as 500 kg of dried fruits per ha (without fertilizers).

**Handling after harvest** The fruits should be carefully dried. In Ethiopia, they are usually pierced near the top, strung on a rope and hung to dry in the sun. If the fruits are not properly dried, or are mixed with immature ones, the end product is of poor quality.

**Genetic resources** Germplasm collections or breeding programmes for korarima are not known. Germplasm collection and conservation, *in situ* and *ex situ*, is recommended because of the rapid degradation and destruction of mountain forests.

**Prospects** *Aframomum corrorima* will probably remain of some importance as its aromatic seeds will continue to be attractive. However, large-scale cultivation for its seeds is not expected. Although not yet in direct danger of extinction, korarima, like all *Aframomum* species, deserves to be part of germplasm collections.

**Major references** 2057, 2058, 2059, 2060, 2061, 2062

**Other references** 2063, 2064

**Sources of illustration** 2062

**Authors** P.C.M. Jansen

## ALYSICARPUS OVALIFOLIUS (Schumach.) J.Léonard

**Protologue** Bull. Jard. Bot. État. Brux. 24(1): 88, t. 11 (1954).

**Family** Papilionaceae (Leguminosae - Papilionoideae, Fabaceae)

**Chromosome number** $2n = 16$

**Synonyms** *Hedysarum ovalifolium* Schumach. (1827), *Alysicarpus vaginalis* auct. non (L.) DC.

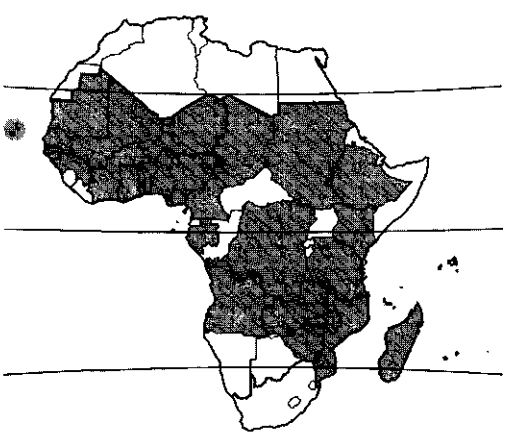
**Origin and geographic distribution** *Alysicarpus ovalifolius* is widespread in West and East tropical Africa, from Cape Verde and Mauritania east to Ethiopia and Kenya and south to Angola, Zimbabwe, Mozambique and Madagascar. It is more common in West Africa than in East Africa, and is particularly common in wooded Sahelian and Sudanese savanna regions. It is also a weed of cropland. Elsewhere, it occurs in tropical Asia, from Afghanistan and India to Vietnam and Indonesia. It has been introduced in the United States.

**Uses** *Alysicarpus ovalifolius* provides a protein-rich fodder and a palatable feed for livestock grazing in rangelands. In Niger, it is a valuable component of vegetation collected and traded as fodder.

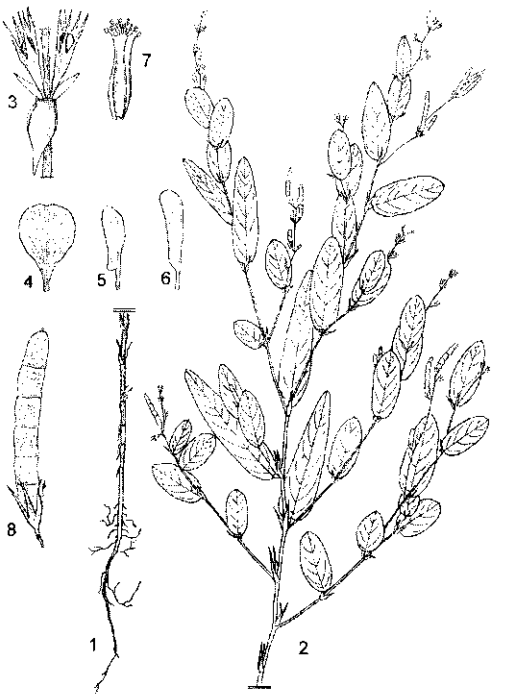
In Nigeria, it is reported as a wound medicine.

**Properties** N and P concentrations are 2.9–4.1% and 0.18%, respectively. *In vitro* digestibility of the dry matter is 69% during the wet season. The leaves disintegrate during the dry season, which makes haymaking difficult.

**Description** Erect or spreading annual herb, sometimes woody at the base, 20–60 cm tall; stems puberulous or pubescent, becoming almost glabrous with age. Leaves alternate, unifoliolate; stipules lanceolate, 0.5–2 cm long; petiole 2–8 mm long, channelled; stipels 0.5–1.5 mm long; petiolule 0.7–1.5 mm long; leaflet elliptical or oblong to narrowly lanceolate, 1–10 cm × 0.5–3 cm, subcordate at base, acute to emarginate and mucronulate at apex, margins entire, finely puberulous and with some hairs on the veins below. Inflorescence a terminal or leaf-opposed pseudoraceme, sometimes paniculate, very lax, the internodes between the 3–7 pairs of flowers long; peduncle 3–4 cm long, rachis 3–11 cm long; bracts ovate-lanceolate, up to 5 mm long, scarious, deciduous. Flowers bisexual; pedicel 1–2 mm long; calyx with 1.5–2 mm long tube and 5 narrowly triangular lobes 3–4 mm long, upper 2 connate except at apex, puberulous or pubescent; corolla with obovate, clawed, orange-buff to pink or reddish-violet, rarely whitish standard 4–6 mm × 3–4 mm, 2 obliquely oblong, purplish-mauve wings 5–5.5 mm × 1–1.5 mm, and pale greenish keel 5–6.5 mm long; stamens 10, alternately long and short, 9 connate into a tube 5–6 mm long, 1 free; ovary superior, linear, ca. 3 mm long, 1-



*Alysicarpus ovalifolius – wild.*




*Alysicarpus ovalifolius – 1, lower part of plant; 2, upper part of plant; 3, part of inflorescence with 2 flower buds; 4, standard; 5, wing; 6, keel; 7, stamens; 8, fruit.*
*Redrawn and adapted by M.M. Spitteler.*

celled, style filiform, ca. 3 mm long, stigma capitate. Fruit a linear-oblong pod 18–25 mm × 2–2.5 mm, indehiscent, 2–8-jointed; joints subcylindrical, 2.5–4 mm × 2–2.5 mm, with raised reticulate ridges, puberulous. Seeds oblong-ellipsoid, slightly compressed, ca. 2.5 mm × 1.5 mm × 1.2 mm.

**Other botanical information** *Alysicarpus* comprises about 25 species of the Old World tropics, with a few species introduced and naturalized in tropical and subtropical America and Australia. *Alysicarpus vaginalis* (L.) DC. (alyce clover), closely related to *Alysicarpus ovalifolius*, is an important forage in various parts of the world. It is perennial and has a more dense inflorescence. In East Africa, particularly on the coast of Kenya and in Zanzibar, the differentiation between the 2 species is not always clear, and they are also probably confused elsewhere. It has been suggested that the two species hybridize and that they should have infraspecific ranks.

**Growth and development** *Alysicarpus ovalifolius* has root nodules which fix nitrogen effectively. It flowers during the rainy season and sets fruit about one month later. It stays green into the early part of the dry season.

**Ecology** *Alysicarpus ovalifolius* usually grows in savanna, and is also frequently found on cultivated and fallow land, preferring sandy soils, from sea-level to 900 m altitude. It has medium drought tolerance and can grow in areas receiving 200–600 mm annual rainfall.

**Propagation and planting** *Alysicarpus ovalifolius* is easily propagated by seed. However, hardseededness is present. The 1000-seed weight is 3.5 g.

**Management** *Alysicarpus ovalifolius* is not used in sown pastures and is not cultivated, but is eaten by herbivores in its natural habitat or as a harvested weed. It responds to P fertilizer on sandy soils.

**Genetic resources** Germplasm collections of *Alysicarpus*, including *Alysicarpus ovalifolius*, are held at ILRI in Addis Ababa, Ethiopia (about 70 accessions), and some smaller ones in Kenya. Outside Africa, *Alysicarpus* germplasm collections are present at CSIRO, St. Lucia, Queensland, Australia (about 100 accessions) and at CIAT, Cali, Colombia (about 300 accessions).

**Prospects** *Alysicarpus ovalifolius* is an important rangeland legume and also occurs on disturbed land. It provides high quality livestock feed to during the rainy season and early part of the dry season. There is no commercial seed production and it is not used for grassland improvement, although this aspect deserves more attention given its easy propagation and nitrogen-fixing ability.

**Major references** 2107, 2199, 2200, 2201, 2202, 2203, 2204

**Other references** 2198

**Sources of illustration** 2205

**Authors** L. 't Mannetje

## AMPELOPTERIS PROLIFERA (Retz.) Copel.

**Protologue** Gen. fil.: 144 (1947).

**Family** Thelypteridaceae

**Chromosome number** $2n = 72$

**Synonyms** *Hemionitis prolifera* Retz. (1791), *Goniopteris prolifera* (Retz.) C.Presl (1836), *Ampelopteris elegans* Kunze (1848).

**Origin and geographic distribution** *Ampelopteris prolifera* is widely distributed in the Old World tropics, in Africa and tropical mainland Asia to north-eastern Australia and New Caledonia. In Africa it is known from Senegal, Guinea, Cameroon and a large area in the east and south-east, from Tanzania south to Malawi, Zambia, Zimbabwe, Mozambique and eastern South Africa, but it probably occurs in many other regions as well. It is also found in Madagascar and the Mascarene Islands.

**Uses** Although not often collected, young fronds of this fern are eaten as a fresh or cooked vegetable in India, where they are considered inferior to *Diplazium* fronds, which are more commonly eaten. They are laxative. In Tanzania, the leaf-sap is drunk in a mixture with *Hypoestes aristata* (Vahl) Sol. ex Roem. & Schult. to treat meningitis and encephalitis. *Ampelopteris prolifera* is also used in traditional medicine in India. It is sometimes grown as an ornamental.

**Properties** A leaf extract of *Ampelopteris prolifera* showed antiviral activity against cucumber mosaic virus in *Chenopodium amaranticolor* Coste & Reyn.

**Botany** Large, scrambling (up to 4 m long) herb with proliferous buds scattered along the rachis of fronds, developing into new plants; rhizome short-creeping, 4–10 mm in diameter. Leaves closely spaced, arching; petiole 12–50 cm long, pale brown, glabrous; lamina narrowly lanceolate to narrowly elliptical, 27–150 cm × 9–26 cm, pinnate, apex indeterminate, papery, both surfaces glabrous; pinnae numerous, the basal pairs distant, the distal ones more closely spaced and smaller, oblong, 10–15(–20) cm × 1.5–2 cm, base truncate to subcordate, subsessile,

apex acute to acuminate, margin crenate; fronds from plants formed by proliferation on buds much smaller. Sori circular to elongate, 4–12 on each side of the pinna lobe, without indusium, with orange capitate paraphyses, at maturity uniting with adjacent sori. Spores closely and irregularly spinulose.

Fern specialists disagree about the delimitation of genera within the large family *Thelypteridaceae*. As a result, the species treated here is found in the literature under a great variety of names; besides those already mentioned it has also been named in the genera *Cyclosorus*, *Dryopteris*, *Meniscium*, *Phegopteris*, *Polypodium* and *Thelypteris*. Sometimes the monotypic genus *Ampelopteris* is considered as a subgenus of the large genera *Cyclosorus* or *Dryopteris*.

The plants are usually sterile. The sori are produced particularly during dry periods. The freely proliferating buds result in effective local dispersal. It has been suggested that the plant spreads along river systems by flood waters breaking off fronds and depositing them on banks further downstream.

**Ecology** *Ampelopteris prolifera* grows mostly in full sunlight and is often found scrambling amongst tall grasses, sedges or shrubs in freshwater swamps, or beside rivers, ponds and lakes, up to 1250 m altitude. It requires permanent moisture; the rhizome is often found growing in water.

**Management** Fronds of *Ampelopteris prolifera* are probably only collected from the wild.

**Genetic resources and breeding** Neither germplasm collections nor breeding programmes are known for *Ampelopteris prolifera*. Since it is widespread and rather common, it is not liable to genetic erosion.

**Prospects** *Ampelopteris prolifera* may have prospects as a vegetable in Africa. There is a need for research into the nutritional value of the leaves and cultivation requirements of the fern as a vegetable crop. Propagation of the fern should not present too many problems because the proliferous buds make vegetative propagation easy.

**Major references** 2108, 3859, 5668, 5669, 5670

**Other references** 5671, 5672, 5673, 5674, 5675, 5676, 5677

**Authors** W. de Winter

## AUCOUMEA KLAINEANA Pierre

**Protologue** Bull. Soc. Linn. Paris, n.s. 1: 1241 (1896).

**Family** Burseraceae

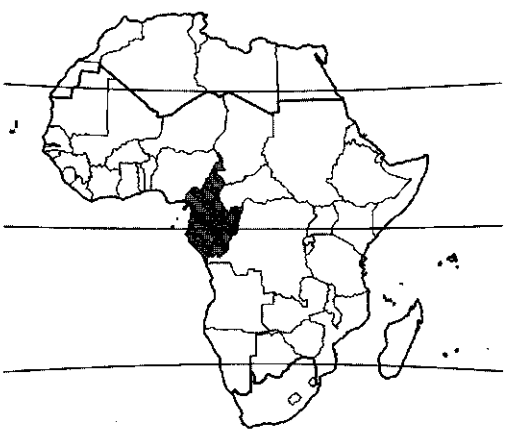
**Chromosome number** $2n = 26$

**Vernacular names** Okoumé, Gaboon mahogany (En). Okoumé (Fr).

**Origin and geographic distribution** *Aucoumea klaineana* occurs naturally in western and central Gabon and in continental Equatorial Guinea, south to Congo, where it is restricted to the Chaillu and Mayombe Massifs. There are small natural stands in southern Cameroon, near the border with Equatorial Guinea. Its natural occurrence in Nigeria, near the border with Cameroon, needs confirmation.

Okoumé has been planted for timber both within its natural range in Gabon and Cameroon, and elsewhere in Cameroon and Côte d'Ivoire. Small-scale planting trials have been made in Congo, Democratic Republic of Congo, Ghana, Madagascar, Indonesia, Malaysia, Suriname and French Guiana.

**Uses** Okoumé is one of the best timber species for plywood. It is a major commercial timber in Gabon and Equatorial Guinea, representing more than 70% of timber production, while it is of lesser importance in Congo. It is made into blockboard, particle board and veneer, and is widely used in boat building for decorative interior panelling and for exterior applications. The wood is also suitable for light interior construction, carpentry, furniture, sports equipment, cigar boxes and packing cases. Logs are traditionally used for the construction of canoes. The wood can be used as firewood and is suitable for the produc-



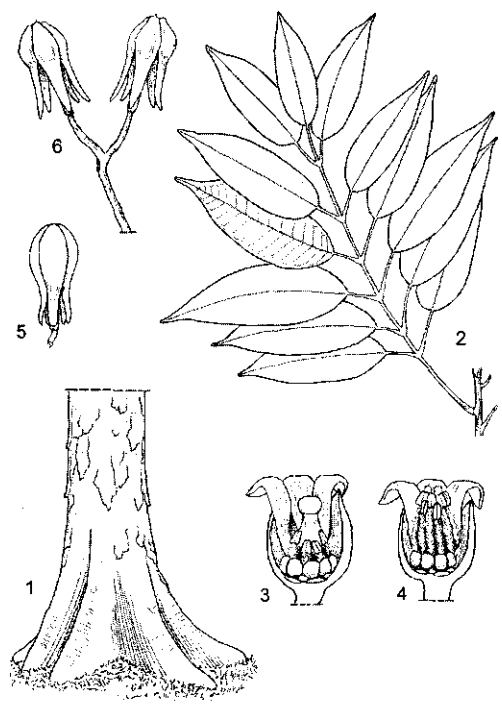
*Aucoumea klaineana – wild.*

tion of pulp for papermaking.
Bark resin is used for torches and oil lamps in Gabon and Equatorial Guinea. It is also applied to treat superficial wounds and abscesses. The astringent bark is used to treat diarrhoea.

**Production and international trade** Okoumé timber is mainly exported as logs to Europe. According to ITTO (International Timber Trade Organization), log exports from Gabon and Congo in 1998 were 2.3 million $m^3$ and 49,000 $m^3$ respectively, and for 1999 2.0 million $m^3$ and 14,000 $m^3$. The export price from Gabon increased from US$ 55 per $m^3$ in 1998 to US$ 82 per $m^3$ in 1999. Gabon exported 38,000 $m^3$ sawn okoumé in 1999 with a value of US$ 112 per $m^3$.

**Properties** Okoumé is a lightweight, comparatively soft hardwood. At 12% moisture content, the density is (320–)430–450(–570) kg/$m^3$, the modulus of rupture 66–86.5 N/$mm^2$, modulus of elasticity 7800–8300 N/$mm^2$, compression parallel to grain 35 N/$mm^2$, shear 5.1–5.7 N/$mm^2$, cleavage 14.3 N/mm tangential and Janka side hardness 2490 N.
Shrinkage rates from green to 12% moisture content are 1.8% radial and 3.2% tangential for non-steamed wood, and 2.0% radial and 3.3% tangential for steamed wood. Okoumé dries rapidly, with little degrade or defects in either air or kiln drying.
It is easy to work with both hand- and machine tools, but worked surfaces tend to be woolly, so cutting edges must be kept sharp. The wood contains up to 0.3% silica and sawing requires tungsten-carbide-tipped cutters as saw teeth blunt rather quickly. When planing, an angle of 20° is necessary to prevent tearing. The wood responds well to sanding, can be nailed without pre-boring, and glues and stains well. It can be polished to a lustrous surface. Dimensional stability is fair, and seasoned wood is reported to move moderately after manufacture. Okoumé is often rotary-cut for plywood; figured wood is sliced into highly decorative veneers for panelling and cabinetmaking.
Okoumé has little natural resistance to decay. Logs are susceptible to forest longhorn beetle attack. While the sapwood is readily attacked by *Lyctus* beetles, the heartwood is resistant, but susceptible to termites, marine borers and fungal attack. The heartwood is impermeable to preservatives. For plywood which may come into contact with moisture, glues containing fungicides are used. The energy value of the wood is 29,970 kJ/kg.
Several terpenoids are present in bark resin, including α-terpineol and β-phellandrene and several tetracyclic and pentacyclic triterpenes.

**Description** Dioecious, medium-sized to large evergreen tree up to 50(–60) m tall; bole cylindrical, often contorted and bent, up to 110(–240) cm in diameter, with buttresses up to 3 m high, and clear of branches up to 21 m; bark 0.5–2 cm thick, greyish to orange-brown, smooth and spotted with white, yellow, orange or red bands (resulting from lichens) in young trees, detaching in more or less thick rectangular brown scales revealing orange bark in adult trees, lenticellate, slash strongly resinous, pinkish-red, fibrous; crown rather open structured. Leaves alternate, imparipinnate; stipules absent; rachis up to 40 cm long; leaflets 7–13, petiolule up to 4 cm long, blade ovate to oblong, 10–30 cm × 4–7 cm, rounded at base, acuminate at apex, margin entire, leathery. Inflorescence an axillary or terminal panicle up to 20 cm long; male inflorescence comprising up to 5 times more flowers than the female. Flowers unisexual, regular, 5-merous; sepals lanceolate, up to 5 mm long, tomentose, greenish; petals




*Aucoumea klaineana –1, base of bole; 2, leaf; 3, female flower, front sepals and petals removed; 4, male flower, front sepals and petals removed; 5, fruit with opening valves; 6, fruits after dropping of valves.*
*Redrawn and adapted by M.M. Spitteler.*

spatulate, 5–6 mm long, tomentose on both sides, whitish; extra-staminal disk present consisting of 2-lobed nectaries; male flowers with 10 stamens and rudimentary pistil; female flowers with 10 staminodes and a superior, 5-locular ovary, each locule with 2 ovules but only 1 ovule developing. Fruit a capsule up to 5 cm × 3 cm, opening with 5 valves from the base, 5-seeded. Seeds enclosed by endocarp ('pyrenes'), ovoid extending into a wing 2–3 cm × 0.5 cm. Seedling with epigeal germination; cotyledons suborbicular, thin and foliaceous.

**Other botanical information** *Aucoumea* is monotypic, and characterized by its extra-staminal disk and dry, dehiscent fruit (pseudocapsule), which after opening releases 5 seeds covered by a winged endocarp.

**Anatomy** Wood-anatomical description:
– Macroscopic characters:
Heartwood salmon pink to pale pinkish-brown or reddish-brown, darkening to a mahogany-like colour upon exposure to light, not clearly or clearly demarcated from the white to pale grey sapwood. Grain slightly interlocked, occasionally straight, curly or wavy. Texture medium to moderately fine; quarter-sawn surfaces with a striped or mottled figure. Growth rings distinct.
– Microscopic characters:
Growth rings usually distinct. Vessels diffuse, 7–9/mm$^2$, solitary or in radial multiples of 2–3, mean tangential diameter 170–200 µm; perforations simple; intervessel pits large (11–12 µm); vessel-ray pits larger than the intervessel pits; tyloses sometimes present. Fibres 1200–1400 µm long, mostly septate, thin- to thick-walled. Parenchyma scarce, scanty paratracheal. Rays 4–5/mm, 2–3-seriate, heterocellular with 1–2 rows of upright and/or square cells and procumbent body cells. Silica bodies present in ray parenchyma.

**Growth and development** Okoumé is shallow-rooted, with virtually no taproot. At 6–12 years, populations become organised into 'biological cells' through joining root grafts. When 10–25 years old, natural and planted populations segregate into dominant and suppressed trees. Trees reach an average height of about 10 m in the first 4 years; from 10–50 years, the growth rate of dominant trees is about 1 m per year, and eventually they reach a height of about 50 m. Suppressed trees grow very slowly and reach 15 m in 50 years. Growth in bole diameter is variable and depends on age, stand density, site fertility, hierarchical position of the tree and thinning rates. In coastal Gabon, bole diameters of 30–80 cm after 50–60 years for dominant trees and 10–40 cm for suppressed trees have been recorded. The mean annual diameter increment for dominant trees gradually decreased from 1.4 cm (7–12 years old) to 0.7 cm (50–60 years old) and for suppressed trees from 0.6 cm (5–20 years old) to 0.1 cm (10–40 years old). Other studies at different sites of inland Gabon recorded mean bole diameter growth rates of 0.5–0.7 cm/year, without taking into account the presence of dominant and suppressed individuals.
New leaves appear from September to December and are bright red for one week. Trees start to flower when they are about 10 years old, but fruiting only begins after 15 years. Flowering starts in August and lasts for 1–2 months depending on weather conditions. Individual flowers last for a few days and are pollinated by bees and flies. Fruiting starts in September; fruits are fully grown in about 40 days, but mature after about 80 days. Fruiting is annual, but large quantities of seeds are produced only every 2–3 years. A healthy, dominant mature tree can produce up to 20,000 seeds. Seeds are wind-dispersed up to 80 m from the parent tree.

**Ecology** Okoumé occurs naturally from sea-level to about 600 m and occasionally to 1400 m altitude in areas with a mean annual rainfall of 1200–3000 mm and a marked dry season (less than 50 mm/month) from June to August/September, during which evaporation is reduced by the relatively low temperatures and high relative humidity. Mean annual temperatures range from 23–26°C, with mean maximum temperatures of the hottest month 32–36°C, and mean minimum temperatures in the coldest month 10–15°C. The natural distribution of *Aucoumea klaineana* is directly related to rainfall. In the north-east of Gabon, a second dry season (during the fruiting period) accounts for the absence of the species there, whereas in the south of Gabon the annual rainfall of less than 1200 mm is the limiting factor.
Okoumé is a long-lived pioneer of, in particular, large forest clearings and fire-protected savanna edges, where it often becomes mono-dominant. It requires full sun to grow well. Seedlings and saplings can, however, survive in shade. Huge individuals occur in what seems to be virgin forest, but is in fact old secondary forest.
Okoumé grows well on a wide range of acid soils (such as ferralitic arenosols, ferralitic soils, podzoluvisols) developed on various substrates. It can grow on infertile sandy soils but prefers fertile, deep sandy-clay-loams. It can tolerate a certain degree of impeded drainage, but not long

periods of waterlogging.

**Propagation and planting** Seeds lose viability within 1 month in the field, but can be stored at 4°C in airtight containers for up to 3 years after being dried to 8% moisture content. The mean 1000 seed weight is 98 g. Propagation by seed is the preferred method. Seeds do not require pre-treatment and can be sown directly in polythene bags (20–30 cm high, 10–15 cm in diameter) filled with a mixture of sand and clay. The addition of NPK fertiliser is recommended. Two seeds are placed per bag; one seedling is selected after 3–4 weeks. After 2.5 months, the seedlings are 20–25 cm tall, have 5–7 simple leaves and are ready for transplanting. Propagation by grafting and cuttings is possible.

**Management** Good regeneration requires a sufficient number of seed trees, large canopy openings or clearings (> 2500 $m^2$) and clean soil during the fruiting season. These conditions are found in shifting cultivation or in logged areas (e.g. log yards and wide logging tracks). Selective logging or natural tree fall events do not produce sufficiently large canopy openings. If site conditions are favourable, okoumé dominates regrowth.

Two main site preparation methods are used for establishing plantations. The first is mechanised clear felling, in which existing woody vegetation is cleared using bulldozers and placed into windrows and burned. Seedlings are planted between the windrows. The second consists of cutting the vegetation to 50 cm above the ground to allow resprouting and regrowth. Seedlings are planted in lines cut through the regrowth. In both methods, existing large trees are killed. Recommended spacings for seedlings are from 625–950 trees/ha. It is necessary to eliminate climbers, especially *Mikania* species, and trees such as *Musanga cecropioides* R.Br. ex Tedlie, which competes for light and space, for up to 5 years after planting. Thinning in both natural and artificial stands is advisable but should be conducted carefully to avoid increased sensitivity to black canker attack resulting from lateral illumination of the stem. In both mixed and almost pure stands, thinning is beneficial for diameter growth, but the resulting extractable wood volume may vary. Suppressed trees are more responsive to thinning than dominant ones. In almost pure stands, thinning should be restricted to those young stands of less than 15 years, because in older stands thinning will remove potentially commercial volumes of wood.

In plantations, a thinning regime to reduce stem density to 350 stems/ha after 5 years, 200–250 stems/ha after 10 years and 150 stems/ha after 15 years is recommended. If resources only allow 2 thinning operations, stand density can be reduced to 250–300 stems/ha after 5 years and 150 stems/ha after 13 years. In all cases, thinning should involve girdling okoumé trees, or girdling and poisoning other species, taking care to avoid intense bole illumination of lower strata trees. Okoumé trees should not be poisoned because of the risk of affecting adjacent trees via the connected root systems.

**Diseases and pests** Okoumé is attacked by various pathogens, which are only serious in pure stands. The most important disease is black canker, a complex infection which begins with a primary infestation of scale insects (mainly *Asterolecanium pustulans*) spread by ants (*Crematogaster*, *Oecophylla*). Subsequent bark injuries are then infested by a secondary fungal pathogen, *Botryodiplodia theobromae*, resulting in an external proliferation of smut which blackens the bark and causes abnormal resin secretion. Very dense or severely thinned plantings and regrowth on abandoned human settlements are particularly prone to black canker. The problem can be avoided by good silvicultural practices, such as selecting a suitable planting site, adequate spacing and careful thinning. Seedlings and young plants are attacked by psyllids (*Pseudophacopteron* spp.) and centipedes, although serious infestations only occur in badly managed nurseries and only affect young plantings. During December and January, the foliage of both young and adult trees is often attacked by caterpillars of the moth *Pleuroptya balteata*, sometimes resulting in total defoliation of pure stands, but trees only suffer a reduction in growth. Locally, elephants cause serious destruction in young and pure stands.

**Harvesting** Only 1 or 2 okoumé trees per ha are usually extracted in mixed stands. Logs float and are commonly transported by river. During seasonally low river levels or where there are no rivers, logs are transported by road or rail.

**Yield** In established plantations, the estimated potential yield varies from 7 $m^3$/ha/year at 43 years on a moderately fertile site without thinning, to 11 $m^3$/ha/year at 32 years on a fertile site with thinning. However, actual production is lower because at least 30% of trees above minimum felling diameter (60 cm) are usually not suitable for timber due to their poor shape. The yield potential in pure natural stands can be 5.5–7.5 $m^3$/ha/year, but commercial yields are 1–2

$m^3$/ha/year due to selective logging.

**Handling after harvest** 80% of okoumé timber is peeled for plywood production. It is considered one of the best woods for this purpose. Peeling can be performed with or without controlled steaming or seasoning, although the latter increases the overall quality of end products.
Sawn timber is becoming important as both Congo and Gabon are attempting to develop their wood-processing capacities. While good quality logs are exported, or locally processed for plywood, lower grades are now used for sawn timber.

**Genetic resources** In order to safeguard the genetic diversity and sustained production of okoumé, stands should be identified and protected throughout the natural range of the species. Special attention should be given to natural stands not having a long history of exploitation. Field experiments indicate poor performance of provenances from sites having a long history of exploitation.

**Breeding** There are currently no major selection and breeding programmes as all planting has ceased, the current trend favouring natural regeneration. However, the few studies on provenance and progeny testing revealed large variability. This diversity at the provenance/progeny level is confirmed by recent genetic studies, indicating that there are possibilities to select better planting material.

**Prospects** Okoumé will remain a major commercial timber for Gabon and Equatorial Guinea, but its climatic requirements restrict its importance elsewhere. Breeding and selection programmes are needed.

**Major references** 5610, 5611, 5612, 5613, 5614, 5615, 5616, 5617, 5618, 5619

**Other references** 5608, 5620, 5621, 5622, 5623, 5624, 5625, 5626, 5627, 5628, 5629, 5630, 5631, 5632, 5633, 5634, 5635, 5636, 5637, 5639

**Sources of illustration** 5609 (fruit with opening valves, fruit after dropping of valves), 5625 (female flower, front sepals and petals removed, male flower, front sepals and petals removed), 5637 (base of bole), 5638 (leaf)

**Authors** J.L.C.H. van Valkenburg

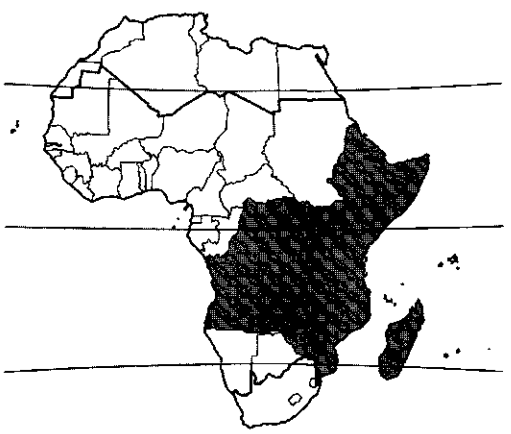
## CATHA EDULIS (Vahl) Forssk. ex Endl.

**Protologue** Ench. bot.: 575 (1841).
**Family** Celastraceae
**Chromosome number** $2n$ = unknown
**Synonyms** *Celastrus edulis* Vahl (1790), *Catha inermis* J.F.Gmel. (1791).

**Vernacular names** Khat, qat, kat, Arabian tea, Abyssinian tea, Bushman's tea (En). Khat, kat, qat (Fr). Katyna (Po). Mlonge, miraa, murungu (Sw).

**Origin and geographic distribution** Khat is indigenous to the evergreen montane forests in eastern Africa, from Eritrea south to South Africa (Cape Province) and Swaziland. The primary centre of origin is assumed to be in the south-western highlands of Ethiopia. According to 14th Century Arabic chroniclers, khat was cultivated extensively in the mountains of Yemen and also near Harer in Ethiopia at that time. It may have been introduced into Yemen from Ethiopia in the 6th Century AD, some 600 years earlier than coffee (*Coffea arabica* L.), but was not known to the West until the end of the 18th Century. Its regular use as a stimulant is confined largely to Muslim communities of southern Arabia and eastern Africa. Yemen, Ethiopia and Kenya are the main khat growing countries, but it is also collected from the wild or cultivated in several other eastern and southern African countries and in Madagascar.

**Uses** Khat is primarily used as a masticatory. Fresh young leaves, and sometimes the tender shoot tips, are chewed for their stimulating and mildly intoxicating effects. As more leaves are added, a wad is formed which is stored in the cheek. This is slowly chewed until all juices are extracted and the residue is expectorated or swallowed. Chewing is accompanied by drinking large quantities of cold water and sometimes also by smoking cigarettes or water pipe.
Khat chewing is an age-old habit in rural areas to alleviate fatigue during fieldwork or to enliven religious and family gatherings. Occupational



*Catha edulis – wild and planted.*

groups, such as drivers of motor vehicles, merchants and students, may use it for its energizing effect and to stay awake. In recent years, khat chewing has become a major recreational activity during lengthy social gatherings, particularly in Yemen, Ethiopia, Djibouti and Somalia, resulting in a heavy strain on family incomes and an appreciable loss of productive labour. Rapid transport by air enables regular fresh supplies of khat even to emigrant communities from these countries now resident in Europe and elsewhere in the world.

Larger leaves that are too hard for chewing and leaves that have lost their freshness may be dried and pulverized for the preparation of a paste with water, sugar or honey and sometimes also spices. The paste is chewed and swallowed in a similar manner as described for fresh leaves. Dried leaves are also used to prepare an infusion in the same way as tea, e.g. in South Africa, or they may be smoked like tobacco, e.g. in Arabic countries. In traditional African and Arabic medicine the leaves and roots of khat are considered a panacea against all sorts of ailments and diseases. When left to grow into large trees, *Catha edulis* yields a fine timber for furniture and building, called Chirinda redwood in southern Africa. The wood pulp makes excellent blotting paper.

**Production and international trade** Recent statistics on cultivation and production are lacking for the major khat producing countries. In northern Yemen khat has overtaken coffee as the most important cash crop; khat production is said to represent about 50% of the gross domestic product of the agricultural sector. Incomes from khat are extremely high; estimates in Yemen range from 5–10 times the income derived from vegetables. It is also a major source of tax revenues for the government. Unlike coffee, there is very little export. It is grown by thousands of small farmers. The popularity of khat chewing has increased tremendously since the 1970s. In Yemen a large proportion of earnings is spent on khat.

In Ethiopia, the south-east is the principal region of production with some 10,000 ha, but khat is also grown in several other regions of the highlands. In the mountains near Harer, khat has replaced traditional coffee cultivation to an important extent. Khat often accounts for more than 50% of total cash income of the farmers. Total annual production of khat in Ethiopia was estimated at 50,000 t in 1980. A significant part of the khat sold on local markets in south-eastern Ethiopia is exported by road to neighbouring Djibouti and Somalia, or by air from Dire Dawa to several countries in Africa, the Middle East and to Europe. Miraa, as khat is generally called in Kenya, is cultivated mainly in the Meru District on the north-east slopes of Mount Kenya and in the Nyambeni Hills. Most of it is sold to Muslim inhabitants of the northern and coastal regions, but there is also substantial export by air to major European cities. The importation and trade of khat is formally prohibited in some countries, e.g. Saudi Arabia, the United States, Italy, France and Switzerland, but in many others it is legal or at least tolerated, e.g. most African countries, the United Kingdom and the Netherlands. For instance, 2–3 t of khat bundles arrive in London every week from Ethiopia or Kenya. One small (200–300 g) bundle of khat twigs may sell for US$ 8–20 in the street markets of London, Rome or Amsterdam.

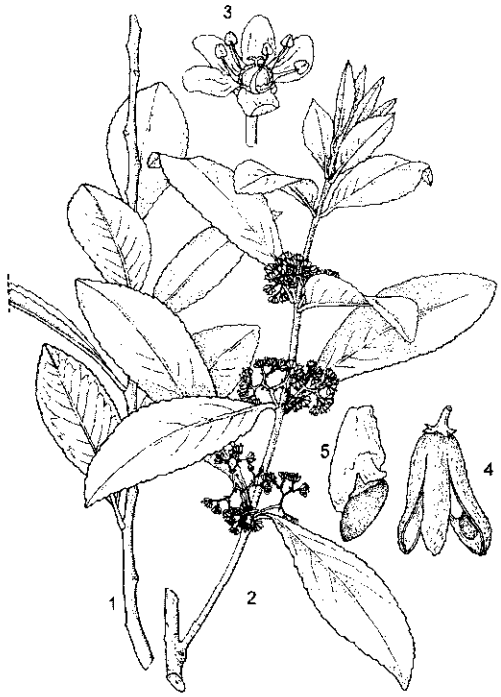
**Properties** Young khat leaves have the following approximate chemical composition per 100 g fresh weight: water 90 g, proteins 5–6 g, fibre 2–3 g, tannins (polyphenols) 1.6 g, calcium 0.3 g and ascorbic acid (vitamin C) 0.2 g. They also contain alkaloids of the phenylalkylamine type, including cathinone (= (–)-α-aminopropriophenone), cathine (= norpseudoephredine) and a number of cathedulines, totalling 0.1–0.8% on dry weight basis. Concentrations of alkaloids in older leaves and other plant parts are much lower. Cathinone is the major determinant of the stimulating effects of khat and is ten times more potent than cathine. Cathinone is highly unstable and its content declines to very low levels within a few days after harvesting. This explains the preference of khat chewers for fresh young leaves, perceived quality being closely correlated with cathinone content. Cathedulines do not contribute significantly to the stimulating effects of khat.

Cathinone stimulates the central nervous system in a manner similar to amphetamines. Initial effects are elation, alertness, euphoria and lack of fatigue. The large volume of leaves needed for even mildly stimulating effects limits the intake of the active substances and makes khat considerably less dangerous than psychoactive drugs available in a chemically pure form. Generally, only a mild degree of dependence on khat develops. Excessive khat chewing can cause insomnia, lack of appetite (anorexia), hypertension and toxic psychosis, and may contribute to socio-economic problems. The astringent tannins present in khat may lead to gastritis, stomatitis, oesophagitis and periodontitis. The high vitamin C content gives khat leaves some nutritional value.

Animal tests showed antispasmodic, analgesic, embryotoxic as well as teratogenic activities of khat. Tests on volunteers who chewed khat on a regular basis showed a significant and progressive rise in blood pressure and heart rate and fall in urine flow rates during a chewing period, and also suggested that khat consumption, especially when accompanied by alcohol and tobacco consumption, might be a potential cause of oral malignancy. The birthweight of children born to khat chewing mothers was significantly lower. Oral administration of the flavonoid fraction isolated from khat produced a significant anti-inflammatory activity against carrageenan-induced paw oedema and cotton pellet granuloma in rats.

The wood of large trees is golden-yellow to brown, lustrous, straight grained, fine and even in texture, strong and moderately hard. It saws and planes well. Density of air-dry wood is about 640 kg/m$^3$.

**Description** Erect, evergreen, glabrous tree up to 25 m tall with dimorphic branching and a small pointed crown, in cultivation a multi-stemmed shrub (0.5–)2.5–6 m tall; bole straight and slender, up to 20 cm in diameter; bark thin, smooth and pale grey-green in cultivated plants, rough on large trees; branches terete, pale to brownish-grey; young twigs usually flattened, dull green to brownish-red. Leaves alternate on orthotropic and opposite on plagiotropic branches, simple; stipules triangular, 3 cm × 1 mm, pale green, caducous, leaving a rim-like scar; petiole terete, 3–11 mm long, pale to dark green; blade oblong to elliptical or obovate, (3.5–)5.5–11 cm × (1–)1.5–4.5(–6) cm, cuneate to attenuate at base, acute to acuminate, sometimes obtuse at apex, margin glandular crenate-serrate, glossy, mature leaf leathery, with reticulate venation. Inflorescence an axillary, regularly dichasial cyme up to 2.5(–3.5) cm long, many-flowered; peduncle 6–12 mm long; bracts usually triangular, up to 2.5 mm long, persistent. Flowers bisexual, regular, 5-merous, 2–4 mm in diameter; pedicel 1–2.5 mm long; sepals basally connate, broadly ovate to suborbicular, 0.5–1 mm long, with fimbriate margin; petals free, elliptical-oblong, 1–1.5 mm long, white or pale yellow, with finely serrulate to fimbriate margin; stamens free, alternating with and slightly shorter than petals; disk intrastaminal, fleshy, shallowly 5-lobed; ovary superior, broadly ovoid, 3-celled, styles 3, short, with small stigmas. Fruit a narrowly oblong, trigonous, pendulous capsule 6–12 mm long, red to brown, dehiscing loculicidally with 3 valves, usually 1–3-seeded. Seeds obovoid, flat on one side, 3–3.5 mm × 1.5 mm, with a large membranous wing 5–5.5 mm × 2.5–3 mm; testa dark-brown, rugose-papillose; embryo with two long, thin cotyledons and small plumule embedded in the endosperm.




*Catha edulis – 1, sterile orthotropic branch; 2, flowering plagiotropic branch; 3, flower; 4, dehisced fruit; 5, seed.*
*Redrawn and adapted by W. Wessel-Brand.*

**Other botanical information** The genus *Catha* consists of one highly polymorphic species. No infraspecific taxa are recognised in *Catha edulis*, but there are several cultivated forms. In Ethiopia, farmers distinguish several cultivars, including 'Dallota' with small pale green leaves, 'Dimma' with medium-sized red leaves and 'Mohedella' with green to olive-green leaves. In Yemen, khat cultivars are sometimes named after a location, e.g. 'Sabr', 'Reimi', 'Taizi' and 'Mathani', or their coloration.

**Growth and development** Fresh seeds germinate within 15–20 days. Seeds soon lose viability. Few observations have been published on seedling growth, mainly because nearly all propagation is by cuttings taken from orthotropic (alternate-leaved) shoots. Growth of rooted cuttings starts with the emergence of new orthotropic shoots with reddish bark and alter-

nate leaves from buds above the leaf axils. These stems continue to increase in length for some two years before the first lateral branches with plagiotropic growth appear from the axils of the oldest leaves, bearing slightly smaller opposite leaves. Laterals are progressively formed in most leaf-axils on the vertical stems as these get older. The initial reddish colour of the shoot tips and young leaves turns to green at maturity and eventually greyish-white. Laterals do not branch much, but produce inflorescences in the leaf-axils up to the tip of the branch. The whole growth cycle is repeated when new orthotropic branches start sprouting on 4-year old sections of existing vertical stems. Suckers will also develop at the base of stems in response to heavy pruning. Plagiotropic branches are relatively short-lived and are shed within 3–4 years after formation. Flowering generally occurs during the rainy season (July–September in Ethiopia); fruits mature within 4 months after anthesis. Trees raised from cuttings are multi-stemmed right from the start. Wild khat trees have a single bole branching into a number of vertical stems higher up.

**Ecology** In Yemen, Ethiopia and Kenya khat is cultivated in the highlands at 1500–2500 m altitude, where average daily temperatures are 16–22°C (range 6–32°C). Annual rainfall requirements are 800–1000 mm over a period of 4–6 months. Frost and high humidity are growth-limiting factors. Khat can be grown in a wide range of moderately acid to alkaline soils, from sandy loams to heavy clays, sufficiently deep and well drained, with a high organic matter content in the topsoil. It is not salt tolerant.

**Propagation and planting** Cuttings 30–50 cm long, taken from orthotropic branches or suckers near ground level, are the main source of planting material. Cuttings prepared from plagiotropic branches root poorly and do not produce good plants. Cuttings may be rooted in a nursery, but are often planted directly in the field during the rainy season. One or two cuttings are planted upright in a hole, sometimes on previously prepared parallel ridges. Planting distances on fairly level land or gentle slopes are 1.5–2.5 m in rows 2–2.5 m apart. Narrower spacings are used where plants are grown as low shrubs. In Yemen and south-eastern Ethiopia, khat is mostly cultivated on mountain terraces allowing only one row of trees per terrace. In the absence of regular rainfall, plants are irrigated until well established. Khat is predominantly a smallholder crop; farmers intercrop young khat plants with food crops during the first 5–6 years, after which shade from the trees becomes too heavy for intercropping. A mixed cropping system of a few rows of khat alternated with one or two rows of coffee (*Coffea arabica* L.) is not uncommon in Ethiopia.

**Management** Khat is left to grow undisturbed for 3–4 years, until about 0.8–1 m tall. Maintenance includes weeding and cultivation to keep the soil loose, thereby helping to preserve soil moisture. Most leaves are then removed to induce the development of young shoots for a first light harvest. Normal yield levels are reached at 5–8 years after planting. The height of khat trees is maintained at 2.5–5 m by regular pruning. Trees can be rejuvenated by cutting back all stems close to ground level and allowing emerging suckers to develop into new stems so that plantations can be kept productive for 50–75 years without replanting. Supplementary irrigation during the dry season increases yields substantially and produces a crop in the off-season, when market prices are higher. In Yemen, khat cultivation has expanded into areas receiving only 300–400 mm rainfall. Here it is always irrigated from wells. Nitrogen fertilizers or organic manures increase yields significantly, but khat is hardly ever fertilized by small farmers.

In parts of the Central Highlands of Yemen, such as the plains and valleys around Rada', khat is grown as a shrub of about 50 cm tall under intensive management with permanent irrigation and regular applications of fertilizer and pesticides. It starts producing about one year after planting.

**Diseases and pests** Khat is relatively free from serious diseases. The following minor pathogens have been identified on khat trees around Harer in Ethiopia: powdery mildew (*Oidium* sp.), black spot (*Dillsiella pollaccii*), *Septoria* sp., and stem and twig galls caused by bacterial infections (*Diplodia* sp. and *Pseudomonas savastanoi*). Common insect pests on khat in Ethiopia are: the flat-headed borer (*Chrysobothris dorsata*), the leaf eating weevil (*Systates* sp.), and caterpillars of the limabean pod borer (*Etiella zinckenella*) and of *Naddiasa concana* and *Aphilopota panerostigma*, that feed on young leaves and stem tips. Farmers generally avoid applying insecticides for fear of killing a beneficial leaf hopper (*Empoasca* sp.), considered to improve the quality of khat by causing dieback of older shoot tips and so encouraging new shoots to develop. Mole rats (*Tachyoryctes* sp.) cause occasional damage to the main stems of young

trees just below the soil surface.

**Harvesting** Young shoots are picked 2–3 times per week during the season. Harvesting is restricted to the early morning to preserve the freshness of the leaves. Young shoots are broken off and trimmed to a length of about 40 cm, sometimes to 80–100 cm, before tying into bundles of a size sufficient for two hours of khat chewing. A bundle weighing 500 g will provide enough tender leaves and shoot tips (150 g) for a two-hour session of khat chewing. The more tender and juicy the leaves the easier it is to chew them and the higher the stimulating effect. For that reason a bundle of khat twigs should not be older than 2–3 days after harvesting. When grown as a low shrub in Yemen, only 10 cm long tips of twigs, with about three expanded leaves, are picked and tied into small bundles.

**Yield** Khat is often grown for home or local consumption and only harvested when the need arises. Such khat plots are not very productive. In market-oriented khat producing regions of Yemen and Ethiopia, yields can be as high as 2 t of fresh shoots per ha per year for well-managed orchards. Average annual yields in Ethiopia are reported to be 800–1000 kg/ha.

**Handling after harvest** Bundles of shoots or leaves are sprinkled with water and wrapped in banana leaves, or those of other plants, to preserve freshness and packed in plastic bags for transport to market. Khat arriving early in the morning will fetch the highest prices and will also be fit for export. It is a very perishable commodity; bundles older than 24–36 hours lose their value. Growers, merchants and consumers distinguish several quality grades based on origin, time of harvest, colour and tenderness of leaves. Whitish leaves are considered to be of higher quality, but reddish leaves give a stronger stimulating effect.

**Genetic resources** No systematic germplasm collection and preservation programmes exist, but small collections are present in botanic gardens (e.g. at the Agricultural University of Alemaya, Ethiopia). Khat is widespread in its natural habitat in eastern Africa; there appears to be no immediate danger of genetic erosion.

**Breeding** There are no formal breeding programmes. Cultivars selected by farmers over long periods of time are maintained by vegetative propagation.

**Prospects** Khat will continue to be the preferred stimulant for large sections of local and emigrant populations of South Arabia and East Africa because of its perceived euphoric and strong socializing effects. The demand for this product is, therefore, not likely to decrease in the foreseeable future. High incomes derived from the crop will also guarantee a steady supply to local and overseas markets. When consumed in moderation, khat appears to be fairly harmless and a replacement for alcohol, where this is prohibited for religious reasons. However, long-term health hazards, especially when taken in excessive quantities, require further investigation.

**Major references** 2062, 5388, 5389, 5390, 5391, 5392, 5393, 5394, 5395, 5396

**Other references** 3814, 4626, 4750, 5377, 5378, 5379, 5380, 5381, 5382, 5383, 5384, 5385, 5386, 5387, 5398, 5399, 5400, 5401, 5402, 5403

**Sources of illustration** 2062 (flower, dehisced fruit, seed), 5397 (sterile orthotropic branch, flowering plagiotropic branch)

**Authors** H.A.M. van der Vossen

## COFFEA EUGENIOIDES S.Moore

**Protologue** Journ. Bot. 45: 43 (1907).

**Family** Rubiaceae

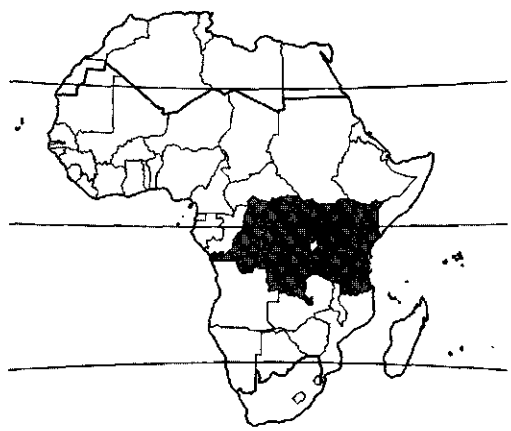
**Chromosome number** $2n = 22$

**Synonyms** *Coffea intermedia* (A.Froehner) A.Chev. (1939).

**Vernacular names** Nandi coffee (En).

**Origin and geographic distribution** *Coffea eugenioides* is native to the highlands of East Africa, where it occurs in the eastern part of the Democratic Republic of Congo, Rwanda, Uganda, Kenya and western Tanzania.

**Uses** Beans of *Coffea eugenioides* have a very low caffeine content and coffee made from them tastes mild and agreeable. *Coffea eugenioides*

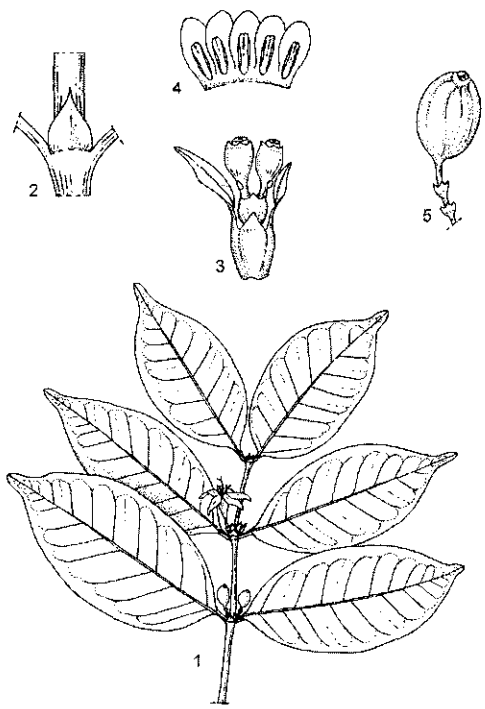


*Coffea eugenioides – wild.*

plays a role in breeding work of *Coffea arabica* L. and *Coffea canephora* A.Froehner, especially in broadening the genetic base and lowering the caffeine content. East African people have a long tradition of using the fruit of *Coffea arabica* and *Coffea canephora*, both from wild and cultivated plants, but they have never used that of *Coffea eugenioides*. Wild plants of the latter, which seemed outstanding in vigour and bean-size, produced progeny with low yields and of no economic value in cultivation.

**Properties** Per 100 g dry matter, the seed of *Coffea eugenioides* contains only 0.3–0.6 g caffeine (compared with 0.6–1.7 g for *Coffea arabica*, and 1.5–3.3 g for *Coffea canephora*), making it an interesting parent in breeding work for low-caffeine coffee.

**Description** Evergreen shrub or small tree up to 5 m tall; young branches usually glabrous, covered with moderately shiny, pale brown to buff bark. Leaves opposite, simple; stipules interpetiolar, triangular, 1.5–2.5 mm long, with an aristate tip up to 3.5 mm long; petiole 0.5–1 cm long; blade elliptical, 2–12 cm × 1–5.5 cm, acute at base, acuminate at apex, entire, papery to subcoriaceous, with or without domatia situated at the bases of lateral veins. Inflorescence an axillary fascicle, usually 1–2 single-flowered inflorescences per axil with stalk up to 6(–10) mm long, sometimes with fascicles of up to 5(–7) flowers. Flowers bisexual, 5-merous; cupular bracteoles usually 2, often with foliaceous lobes, scale-like bracteoles usually present on pedicels; calyx-limb reduced to a rim, shorter than the disk; corolla white, with cylindrical tube 5.5–10 mm long and oblong-lanceolate lobes 5–12 mm × 2–4 mm, acute to obtuse; stamens attached at corolla throat, exserted, erect, with short filaments; disk annular; ovary inferior, 2-locular with a single ovule per locule, style slender, exserted, stigma with 2 divergent arms. Fruit an ellipsoid to roundish drupe 8–10.5 mm × 6–8 mm, rounded at base, greenish becoming red when mature, with a longitudinal groove and (1–)2 pyrenes. Seeds 6–8 mm × 3–5 mm, grooved in inner face, yellowish to greenish-fawn; testa thin, shiny; endosperm horny.




*Coffea eugenioides – 1, flowering and fruiting twig; 2, stipule; 3, 2-flowered inflorescence with old flowers; 4, opened corolla with stamens; 5, fruit.*
*Redrawn and adapted by W. Wessel-Brand.*

**Other botanical information** More than 100 *Coffea* species have been described, mainly from Africa. All species studied are diploid ($2n = 22$), except for the allotetraploid species *Coffea arabica* ($2n = 44$). Phylogenetic relationships of *Coffea* species inferred from chloroplast DNA variation and nuclear ribosomal DNA units confirmed a monophyletic origin of *Coffea*, with major groups presenting a strong geographical correspondence (West Africa, Central Africa, East Africa and Madagascar). Recent investigations by means of molecular markers, gene sequencing and genomic *in situ* hybridization support the hypothesis of an allotetraploid origin of *Coffea arabica* involving *Coffea eugenioides* as maternal progenitor and *Coffea canephora* as paternal progenitor. Other genomic *in situ* hybridization studies, however, indicate the closely related *Coffea congensis* A.Froehner as the paternal progenitor.

*Coffea eugenioides* belongs to the so-called '*arabica-congensis*' complex, together with *Coffea arabica* L., *Coffea congensis* A.Froehner and *Coffea kivuensis* Lebrun. The species of this complex are closely related, which could be a consequence of very recent speciation processes. They are difficult to distinguish morphologically, and it is not possible to reliably differentiate the species on the basis of flowering specimens only. However, fruiting specimens can be identified confidently in almost every case. A study of the variation in morphology of the complex showed that *Coffea kivuensis* is best treated as a species

distinct from *Coffea eugenioides* and not as it has been more commonly known as, a variety of the latter species. It can be distinguished by its larger, obovoid fruits with acute bases and without a longitudinal groove. *Coffea kivuensis* seems more closely related to *Coffea congensis*. The '*arabica-congensis*' complex seems to consist of 2 groups of vicariant species: one group comprising *Coffea arabica* and *Coffea eugenioides*, and the second *Coffea congensis* and *Coffea kivuensis*.

**Growth and development** *Coffea eugenioides* is a common understorey species found in the form of a shrub, usually 2–3 m in height, with more than one main stem. When growing under shade in natural forest, it resembles a miniature *Coffea arabica*: the leaves are similar, but they are smaller and thinner; the flowers also resemble those of *Coffea arabica*, but they are smaller and there are seldom more than 2 or 3 in a cluster. The fruits are not abundant and contain very small beans. When *Coffea eugenioides* is growing in the open (e.g. in living collections) it becomes a compact conical shrub or small tree, with small leaves.

**Ecology** *Coffea eugenioides* is found both in large forests and in small relict forests in the highlands, between 1500 and 2200 m altitude, but penetrates slightly into the lowlands in the Democratic Republic of Congo (Kivu region) and the lowland forests of the Lake Victoria belt. It appears to be tolerant of a wide range of soils and to temporary drought conditions. In some localities in Uganda (Minziro forest, Budongo forest) *Coffea eugenioides* and *Coffea canephora* grow in close proximity, but differ in habitats: the former is restricted to the hillside forests or the drier eastern sides of the forests and grows near forest edges, while the latter is more abundant inside the forests, in hollows that are sometimes waterlogged or in the wetter western sides of the forests.

**Diseases and pests** The two major diseases of coffee, leaf rust (*Hemileia vastatrix*) and coffee berry disease (*Colletotrichum kahawae*) have been observed on *Coffea eugenioides* in natural forests in Kenya. Mites and leaf miners are common on plants in rain forest and are considered pests of secondary importance. Some tolerance is reported to a number of nematodes, leaf miner (*Leucoptera coffeella*) and leaf rust.

**Genetic resources** Surveys of genetic erosion in wild coffee made by IBPGR in the Kenyan forest understorey revealed that 2 of 13 wild coffee sites had disappeared and only 2 out of 13 sites were secure in a national park. The other sites were highly threatened and required further monitoring to assure valuable *in situ* conservation.

In the 1970s, two field gene banks of 23 taxa were established in Côte d'Ivoire for *ex situ* conservation of the diploid African coffee species. *Coffea eugenioides* germplasm is represented by about 1000 accessions originating from 6 wild coffee populations in Kenya. One of these collections is located at 1100 m altitude (at Man on Mount Tonkoui) in accordance with its ecological adaptation. Plants are grafted on to well-adapted rootstocks. A duplicate of this field collection is maintained at the Coffee Research Institute, Ruiru (Kenya). In other countries, a few samples of *Coffea eugenioides* are present in working collections.

Coffee seeds are not considered orthodox because they are not tolerant of dessication or low temperature. They cannot be used for long-term conservation. As an alternative approach, development of an *in-vitro* coffee core collection was initiated at ORSTOM (Montpellier) in the 1990s, representing 21 taxa; unfortunately, introduction of *Coffea eugenioides* was not successful.

**Prospects** Because of the low caffeine content of its beans and its good cup quality, *Coffea eugenioides* may gain some importance in breeding work on *Coffea arabica* and *Coffea canephora*.

**Major references** 3941, 5368, 5369, 5370, 5371, 5372, 5373, 5374

**Other references** 5360, 5361, 5362, 5363, 5364, 5365, 5366, 5367, 5376

**Sources of illustration** 5375

**Authors** A. Charrier

## CONNARUS AFRICANUS Lam.

**Protologue** Encycl. 2(1): 95 (1786).

**Family** Connaraceae

**Chromosome number** $2n$ = unknown

**Synonyms** *Connarus nigrensis* Gilg (1891).

**Origin and geographic distribution** *Connarus africanus* occurs throughout the forest zone of West Africa, from southern Senegal east to western Central Africa, where it is found in Cameroon, Sao Tomé, Equatorial Guinea and Gabon.

**Uses** *Connarus africanus* has several applications in traditional medicine in West Africa. The bark, as a decoction or powder, is applied externally to ulcers and wounds. It is credited with tonic and astringent properties. The root bark is used internally to treat tapeworm infections; a

decoction or infusion of pounded seeds has a similar use. The leaf-sap is used in Côte d'Ivoire with bark sap of *Chrysophyllum perpulchrum* Mildbr. as a nasal instillation to treat fainting. The seeds are occasionally used to bait hooks for fishing. *Connarus africanus* is very occasionally planted as a hedge.

**Properties** The taeniacidal activity has been ascribed to the presence of tannin in bark and seeds. However, in a closely related species from South-East Asia, *Connarus monocarpus* L., the presence of benzoquinones, such as rapanone and embelin, has been demonstrated. Although the phytochemistry of *Connarus africanus* has not been investigated, similar compounds might partly explain the attributed medicinal activities.

**Botany** Liana or lianescent shrub, with lenticellate branches. Leaves alternate, 3-foliolate; stipules absent; petiole 2.5–14 cm long, rachis 1.5–4 cm long; leaflets ovate or elliptical, (4–)6.5–25 cm × 2–9.5 cm, rounded at base, acuminate at apex, entire, papery, glabrous, pinnately veined. Inflorescence an axillary panicle up to 35 cm long, usually many together near ends of branches and then appearing terminal and compound, densely brown-pubescent, up to 50-flowered. Flowers bisexual, regular, 5-merous, heterodistylous; pedicel short, articulate; sepals ovate, up to 4 mm long, glandular punctate; petals usually coherent, narrowly elliptical to narrowly obovate, up to 8 mm long, glandular punctate; stamens 10, united at base, alternately long and short; ovary superior, brown hairy, style longer or shorter than long stamens. Fruit a narrowly obovoid, slightly oblique follicle up to 6 cm long, shortly stiped at base, red, glabrous outside, glandular inside, 1-seeded. Seed ovoid, up to 3 cm long, shining black, with yellowish sarcotesta at base. Seedling with hypogeal germination; cotyledons planoconvex, staying within the testa; first leaves 1-foliolate.

*Connarus* comprises about 75 species and is pantropical. In Africa, 7 species occur. The Central African *Connarus congolanus* Schellenb. closely resembles *Connarus africanus*, but differs in its more leathery leaflets, thicker sepals, petals not connivent, and fruit not stiped and pilose inside.

**Ecology** *Connarus africanus* occurs in rain forest and riverine forest, and sometimes in thickets in savanna.

**Management** *Connarus africanus* is not planted, except in rare instances as a hedge grown from stakes. Bark and seeds are collected for medicinal purposes from the wild.

**Genetic resources and breeding** *Connarus africanus* is widespread and locally common. It is not at risk of genetic erosion.

**Prospects** Phytochemical and pharmacological research is required to evaluate the uses of *Connarus africanus* in traditional medicine.

**Major references** 2105, 5678

**Other references** 5679

**Authors** R.H.M.J. Lemmens

## CRAMBE HISPANICA L.

**Protologue** Sp. pl. 2: 671 (1753).

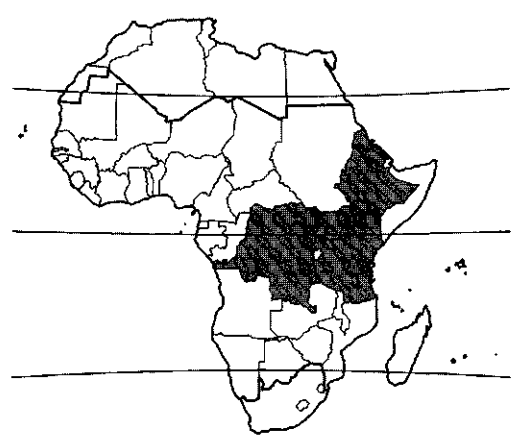
**Family** Brassicaceae (Cruciferae)

**Chromosome number** $2n = 30, 60, 90$.

**Synonyms** *Crambe abyssinica* Hochst. ex R.E.Fr. (1914).

**Vernacular names** Crambe, Abyssinian mustard, Abyssinian kale, colewort (En). Crambé, crambé d'Abyssinie, chou d'Abyssinie (Fr).

**Origin and geographic distribution** *Crambe* is believed to have originated in the Turco-Iranian region and to have spread into the Mediterranean and Europe and through Ethiopia into East Africa. *Crambe hispanica* occurs naturally in Mediterranean Europe, Morocco and the Middle East. Its native distribution extends into the highlands of Ethiopia, Eritrea, Uganda, Kenya, Tanzania, Rwanda and easternmost parts of the Democratic Republic of Congo. In Ethiopia it is traditionally grown on a small scale as a medicinal plant and minor oil crop. Crambe was first tested as an oil crop in the former USSR in the 1930s. From there, interest in crambe as a new, alternative crop spread to Sweden and Poland and later to other parts of Europe, North



*Crambe hispanica* – *wild.*

America and China. Thus, crambe is being developed as a cool-temperate oil crop although it occurs naturally in the subtropics and tropics.

**Uses** Crambe is grown for its seed oil which is rich in erucic acid. Crambe oil is used industrially as a lubricant and cooling agent. Erucic acid is easily modified and its chemical derivatives are valuable raw materials in the production of lubricants (erucamide), plasticizers, surfactants, corrosion inhibitors, rubber additives, nylons, paints, hydraulic and dielectric fluids, pharmaceuticals and cosmetics. The presscake, although rich in glucosinolates, can be used as a feedstuff for ruminants. The presscake is also applied as a fertilizer. Glucosinolates extracted from the seed are being tested pharmaceutically. In Ethiopia, the fruits are used in traditional medicine to treat snake bites. The leaves are eaten in Kenya.

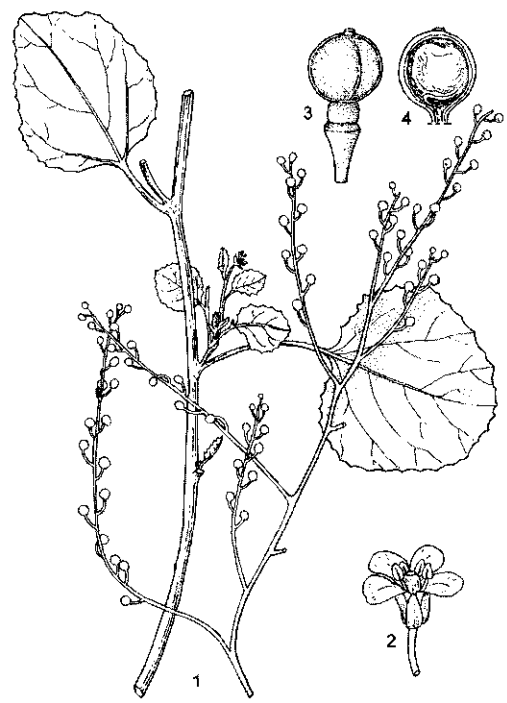
**Production and international trade** Few data on production and trade of crambe are available. Soon after its introduction as an oil crop in Poland it was cultivated there on 25,000 ha, but no recent data are available. In the United States, production increased rapidly to 25,000 t seed from 22,500 ha in 1993, but then declined rapidly again; the main centre of production of crambe is North Dakota. Difficulties in organizing commercial oil extraction and lack of government support have contributed to the decline. More comprehensive recent statistics are not available.

**Properties** The approximate composition of 100 g of crambe fruit is: water 7 g, crude fat 33 g, protein 17 g, crude fibre 14 g, N-free extract 23 g and ash 5 g. Hulls make up about 30 % of the weight of the fruit. Crambe oil has the highest content of erucic acid (50–60%) of all crops; other fatty acids include oleic acid (about 17%), linoleic acid (about 9%) and linolenic acid (about 5%). Nearly all erucic acid in crambe oil is esterized with C-atoms 1 or 3 of the glycerol moiety. It can be selectively hydrolyzed, yielding almost pure erucic acid.

The approximate composition of defatted seed cake made from whole seed is per 100 g dry matter: protein 28 g, crude fibre 22 g, N-free extract 40 g and ash 8 g; 100 g seed cake made from dehulled seed contains approximately: protein 50 g, crude fibre 7 g, N-free extract 36 g and ash 10 g. Crambe cake contains about 5% glucosinolates, which are nitrogen and sulphur containing organic compounds that release cyanogenic acid on decomposition. The main glucosinolate (over 90% of the total) is epi-progoitrin (2-hydroxy-3-butenyl glucosinolate), a stereoisomer of progoitrin which occurs in rapeseed. Glucosinolates and their derivatives are toxic or appetite suppressing to animals, but ruminants exhibit a degree of tolerance. In the United States, the Food and Drug Administration allows the addition of 5% crambe meal to cattle feed. Methods of detoxification have been developed, but the small amounts of epi-progoitrin remaining in detoxified meal may still be toxic or appetite suppressing to monogastric animals, especially pigs. However, from tests with mice it was concluded that crambe may exert protective effects against tumour formation and growth.

**Adulterations and substitutes** The oils of *Brassica napus* L. and *Brassica rapa* L. (rapeseed) both contain large amounts of erucic acid. Cultivars especially rich in erucic acid have been bred. Their erucic acid content is lower than that of crambe, but their yields are higher and they are better adapted to warm temperate climates.

**Description** Annual, much-branched herb; stem erect, furrowed, up to 1.5(–2) m tall, branched in upper parts, base densely hispid to glabrescent, upper parts with scattered hairs or




*Crambe hispanica – 1, lower and upper part of fruiting plant; 2, flower; 3, fruit; 4, upper part of fruit in longitudinal section.*
*Redrawn and adapted by W. Wessel-Brand.*

glabrous. Leaves alternate, lyrate-pinnatifid, variable in shape and size along the stem, 4–15 cm long, densely to moderately hairy on both surfaces or subglabrous; stipules absent; lower and median leaves petiolate, petiole of lower leaves up to 20 cm long, grooved above, hairy, upper leaves sessile or shortly petiolate; terminal lobe large, ovate or reniform, truncate or cordate, margins irregularly crenate-dentate, lateral lobes in 1–2 pairs, much smaller, sometimes absent, elliptical, usually 0.5–2 cm long, upper leaves frequently undivided, acutely ovate to rhombic. Inflorescence a terminal, ebracteate, 20–50-flowered corymbose raceme, in fruit lax, usually branched, up to 40 cm long, sparsely hairy or glabrous. Flowers bisexual, regular, 4-merous; pedicel up to 1 cm long, articulate; sepals elliptical, 1.5–3 mm long, green; petals spatulate, shortly clawed with limb expanded, 2.5–6 mm long, white; stamens 6, distinctly tetradynamous, 2–3 mm long, filaments linear, inner ones usually with teeth near the apex, anthers 0.7–0.8 mm long; ovary superior, consisting of 2 segments, only upper segment developing a seed. Fruit a 2-parted silicula, lower part very short, up to 1 mm long, upper part globose to ellipsoid, 2–3 mm in diameter, straw-coloured, smooth, shiny, indehiscent, 1-seeded. Seed spherical, greenish-brown to yellowish-brown or brown, 1–2.5 mm in diameter. Seedling with epigeal germination.

**Other botanical information** *Crambe*, with about 35 species, is one of the largest genera of the tribe *Brassiceae*. *Crambe hispanica* is included in the section *Leptocrambe* DC., together with 4 other species from the Mediterranean and East African region. In agricultural literature it is generally referred to as *Crambe abyssinica*. The differences (reniform to cordate terminal lobe of the lower leaves and upper fruit part without ribs in *Crambe hispanica* versus obovate to ovate-rhomboid terminal lobe and slightly 4-ribbed upper fruit part in *Crambe abyssinica*) are considered insufficient to distinguish *Crambe abyssinica* as a separate species. However, it is distinguished as a subspecies: subsp. *abyssinica* (Hochst. ex R.E.Fr.) Prina. Two other subspecies are distinguished: subsp. *hispanica* from the eastern Mediterranean region, and subsp. *glabrata* (DC.) Cout. from the western Mediterranean region.

**Growth and development** Crambe has orthodox seeds with usually about 4 months dormancy. Once the dormancy is broken, the seeds take 1–2 weeks to germinate at temperatures of 10–20°C. Germination is retarded below 8°C and inhibited below 5°C. Early growth is rapid. Plants reach the 2-leaf stage 6–12 days after germination and the 6-leaf stage after 15–27 days. Inflorescences develop from the 10–13th node upwards. Flowering starts 33–42 days after germination. Crambe is mainly self-pollinated, but about 15% cross-pollination occurs. Leaf growth virtually stops soon after flowering and the onset of anthesis generally coincides with maximum leaf area index and biomass accumulation rate. Early senescence of the foliage is a major factor in the low yield capacity of crambe, especially because the surface area of the pods is small and can intercept only at most 25–35% of incident radiation. Physiological maturity is reached after about 80 days.

**Ecology** Little is known about the natural occurrence of *Crambe hispanica* in tropical Africa. It is found on grassland and waste ground, and as a weed in agricultural fields at 1200–2600 m altitude.

Crambe is one of the crops which occur naturally in tropical highlands and the hot subtropics that is being developed for cool temperate climates by a concerted breeding effort. Although young seedlings are tolerant of –5.5°C for a few hours, frost is generally not tolerated. The best temperature range for vegetative growth is 10–25°C, but higher temperatures are well tolerated. Crambe can be grown up to 2500 m altitude in the tropics, provided a frost free period of 90 days is assured. For commercial production, an annual rainfall of 800–1500 mm is required. Once established, crambe tolerates periods of drought as long as soil moisture is adequate during the flowering and fruit setting stages. A dry period prior to fruit maturity is beneficial. Crambe is more tolerant of drought than maize, soybean and mustard crops. Crambe grows best on well-drained fertile loamy soils of pH 6.0–7.5. Soils with poor internal drainage should have good surface drainage. Soil crusting can seriously affect germination and seedling growth. Crambe is moderately tolerant of salinity.

**Propagation and planting** Crambe is propagated by seed. The weight of 1000 seeds is about 7 g. Seed rates vary from 10–25 kg/ha. A fine, firm seedbed is required for even germination and vigorous seedling growth. Seed is placed at a depth of 2 cm. Wind erosion should be avoided or controlled as drifting soil easily damages seedlings.

**Management** Fertilizer recommendations for crambe have not yet been developed. Rates recommended for rapeseed can be used. A high plant density is the best way to control early

weeds in crambe. However, weeds may develop later in the maturing crop and cause difficulties with harvesting and moisture content of the seed. Crambe is very sensitive to herbicides and is easily affected by herbicide drift.

**Diseases and pests** The main disease of crambe in North America is *Alternaria brassicola*. Control is possible by treating seed with a fungicide or with hot water (60°C for 20 minutes). Other potential diseases are *Fusarium* wilt, *Sclerotinia* white mould and *Pythium* rot. Susceptibility to tobacco and turnip mosaic virus has been reported. Seedlings may be attacked by flea beetles and aphids. Grasshoppers seem to avoid them when alternative sources of food are available. Other diseases and pests are likely to become more important when crambe becomes an established, widely grown crop.

**Harvesting** When crambe fruits approach maturity, the leaves turn yellow and drop; a few days later the fruits and small branches turn straw-coloured. When the last seed-bearing branches have turned colour, the crop is ready to harvest. Timely harvesting is important to avoid excessive shattering. Swathing may be necessary in an unevenly ripened crop. However, early swathing results in a low erucic acid content of the oil.

**Yield** In the United States, commercial yields of crambe seeds are 1300–2000 kg/ha, but up to 3500 kg/ha has been obtained in trial plantings.

**Handling after harvest** Transport costs of crambe seed are high because of its low bulk density. Dehulling of crambe fruit is possible but more difficult than in fruits of *Brassica* oil crops, and is hard to carry out in the field. Dehulling is not necessary for oil extraction, but the presscake from dehulled fruit has a higher value as cattle feed. Before oil extraction the fruit is crushed and heated. The heating process should be carefully controlled as it has major effects on the palatability and toxicity of the presscake. Subsequently the oil is extracted by mechanical pressing followed by solvent extraction or by solvent extraction alone. Heat treatment or extraction with water of the presscake may improve its quality by reducing its content of antinutritional and toxic substances. However, the treated presscake is still only suitable for ruminants.

**Genetic resources** Genetic variability in cultivated forms of crambe is limited. However, crosses with wild forms of *Crambe hispanica* and several other *Crambe* species yield viable seed, and experimental crosses with *Brassica juncea* (L.) Czern. have given hybrid seedlings through embryo rescue techniques. Substantial collections of *Crambe* germplasm, including *Crambe hispanica*, are maintained at the Victorian Institute of Dryland Agriculture, Horsham, Victoria, Australia and the USDA National Seed Storage Laboratory, Ft. Collins, Colorado, United States.

**Breeding** The potential yield of erucic acid from crambe is still low in comparison with other crops such as *Brassica napus* L. The main objective of breeding programmes is therefore to increase yields. Factors limiting potential yield include photosynthetic efficiency during the grain filling stage. Inheritance of seed yield, however, has been found to be low. Cultivars released include: 'Meyer', 'BelAnn' and 'BelEnzian' in the United States, 'Galactica' in the Netherlands and 'Charlotte' and 'Carmen' in France.

**Prospects** Great steps have been made in the development of crambe as an industrial oil crop for temperate regions. It fits well in crop rotations and can be grown using common practices. However, other crops yielding erucic acid and technologies to separate erucic acid from their oils are also being developed. Advantages of crambe are that it is more tolerant of heat and drought, resistant to flea beetles and it can be combine-harvested without swathing. However, only if research can increase the yield potential of crambe sufficiently to compete with other crops can it become a viable choice for farmers. As there are no indications of day-length sensitivity, it could become a suitable crop for the highlands of tropical Africa.

**Major references** 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076

**Other references** 2065, 2066, 2077, 2078, 2080, 2081

**Sources of illustration** 2079 (lower and upper part of fruiting plant, flower, upper part of fruit in longitudinal section), 2081 (fruit)

**Authors** L.P.A. Oyen

## DACRYODES EDULIS (G.Don) H.J.Lam

**Protologue** Ann. Jard. Bot. Buitenzorg 42: 202 (1932); Bull. Jard. Buitenzorg, ser. 3, 12: 336 (1932).

**Family** Burseraceae

**Chromosome number** $2n$ = unknown

**Synonyms** *Pachylobus edulis* G.Don (1832), *Pachylobus saphu* Engl. (1896).

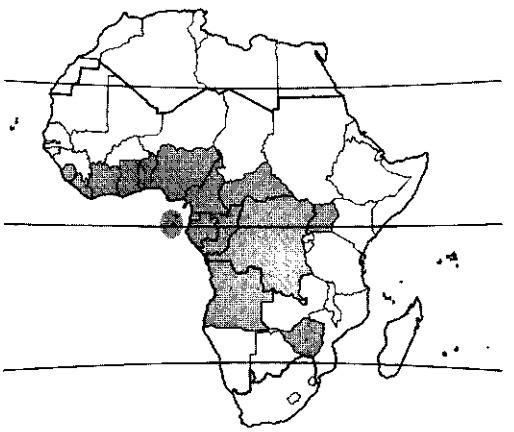
**Vernacular names** Butter fruit tree, bush butter tree, African pear tree, African plum tree (En). Safoutier (Fr).

**Origin and geographic distribution** *Dacryodes edulis* occurs naturally in the countries bordering the Gulf of Guinea. It is grown from Sierra Leone to Angola along the Atlantic and further inland as far as Uganda; it has also been recorded in northern Zimbabwe. The exact natural area of distribution is obscure because *Dacryodes edulis* is much cultivated and naturalized.

**Uses** Butter fruit tree is one of the main tree fruits throughout much of its area of distribution. The oil-rich pulp is eaten after softening by immersion in boiling water for 2–3 minutes, or by heating over embers or a hot plate. A common preservation method is to remove the seed from the fruit, boil the pulp and dry it in the sun.
Concoctions of the leaves are ingested to treat disorders of the digestive tract, toothache and earache. The bark is used to cure dysentery and anaemia, root bark against leprosy; the resin extracted from the bark heals scars and other skin problems. An oil suitable for cosmetics and food can be extracted from the fruit, but this is not yet done commercially.
*Dacryodes edulis* is a useful shade tree in coffee and cocoa plantations. The wood is reported to be nearly as good as African mahogany *(Khaya)*, but is nevertheless mainly used as firewood. It is comparable to that of *Dacryodes buettneri* (Engl.) H.J.Lam, which is more commonly exploited commercially. Nectar from the flowers yields a much appreciated honey.

**Production and international trade** Farm surveys indicate that trees are found on 50–100% of the farms in 7 states of south-eastern Nigeria and on 80–94% of the farms in the humid lowlands of Cameroon, mainly in home gardens, tree crop fields and swidden fields; they are also common in highland areas. The average price in different states of Nigeria ranged widely from US$ 0.03–0.60 per kg of fruit (1994). Home consumption accounts for about 60% of production. In the first half of 1995 nearly 600 t, valued at US$ 244,000, was traded in the humid lowlands of Cameroon. The fruit is a very common sight in Cameroonian market places; much of it is traded across borders into neighbouring countries, e.g. to Gabon, partly because the fruit ripens from June–November north of the equator and from December–April south of it.

**Properties** The fruit flesh is softened by cell-wall-degrading enzymes. At temperatures of 60–85°C this is accomplished in a matter of minutes; at room temperature it takes 7–10 days, with bruising and microbes reducing this period to 3 days. Boiling inactivates the enzymes so that the pulp hardens.

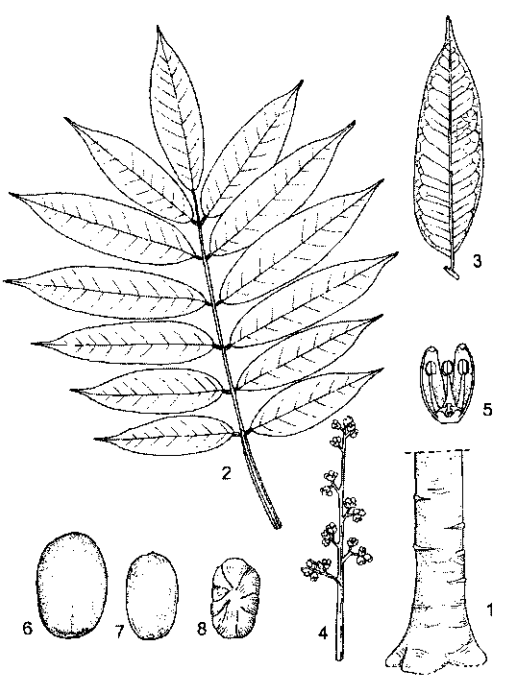


*Dacryodes edulis – wild and planted.*

Fruits vary greatly in size, shape, colour and composition. The pulp to seed weight ratio is around 2–3 for the smaller fruits, but increases to over 5 for the largest. The pulp contains 59% water; per 100 g the dry matter contains: oil 32–44 g, protein 14–26 g, carbohydrates, fibres and other matter 32–38 g, and ash 4–10 g.
The oil content of the fruit pulp is very high: 30–60% on a dry matter basis. Oleic acid (45–60%), palmitic acid (30–35%), linoleic acid (15–20%), and stearic acid (2%) constitute about 95% of the pulp oil. When left standing the oil separates into a semi-solid lower layer and a liquid upper one. The fatty acid composition of the 2 layers is similar. The unsaponifiable fraction of the oil represents about 2%, and consists mainly of sterols (20% - mainly sitosterol), triterpene alcohols (34%) and small amounts of tocopherols. Unlike other oily fruits, the seed oil (content per 100 g dry matter: 10–15 g) is of the same type as the pulp oil, so for extraction it is not necessary to separate pulp and seed. The resulting cake can serve as animal feed.
The fruit contains about 1.5% essential oil. Its main constituents are: myrcene (45%), α-pinene (9%), α-terpineol (8%) and germacrene-D (4%); minor compounds include: E-α-cadinol, δ-cadinol and β-eudesmol.
The wood is yellowish-pink, moderately heavy (density about 600 kg/m$^3$ at 12% moisture content) and moderately elastic; texture moderately coarse. Drying does not usually give problems except for thin boards. The wood is somewhat difficult to work due to the presence of silica, rapidly blunting tools during sawing. Planing may be problematic due to the interlocked grain.

The staining, polishing and gluing properties are good. The timber can be peeled satisfactorily.

**Description** Dioecious, small to medium-sized tree up to 20(–25) m tall; bole up to 70(–90) cm in diameter, straight and cylindrical, often shallowly fluted and low-branching; bark yellowish-grey to grey, often shallowly scaly and with lenticels and horizontal folds, slash brownish-pink, exuding drops of translucent-whitish, aromatic resin; crown much-branched, dense; young branches with a dense indumentum of ferruginous stellate or dendroid hairs. Leaves alternate, imparipinnate; stipules absent; petiole up to 7.5 cm long; leaflets 11–19, petiolule up to 1 cm long, blade oblong to oblong-lanceolate or ovate-lanceolate, up to 20(–30) cm × 6(–8) cm, broadly cuneate to rounded and asymmetric at base, acuminate at apex, margin entire, glabrescent, with 9–15 pairs of lateral veins anastomosing within the margin. Inflorescence an axillary panicle up to 40 cm long, with cymose ramifications, ferruginous-tomentose, with flowers often in clusters of 3 surrounded by bracts; often entire shoot tips becoming floriferous with reduced leaves, giving the impression of a terminal inflorescence. Flowers unisexual, 3-merous; pedicel up 5 mm long; sepals almost free to the base, 3–6 mm long, ferruginous-tomentose outside; petals free, 5–6 mm long, incurved at apex, tomentose outside; stamens 6, slightly shorter than petals, in female flowers smaller and infertile, filaments broadening towards the base; disk annular, slightly lobed; ovary superior, ovoid, vestigial in male flowers, 2-celled with 2 ovules in each cell, style very short, stigma 2–4-lobed. Fruit an ellipsoid drupe 4–12(–15) cm × 3–6 cm, ripening from pinkish to blue-green, purple or brilliant black, 1-seeded; pericarp pulpy, about 5 mm thick; endocarp thin and cartilaginous. Seed oblong-ellipsoid, up to 5.5 cm long; cotyledons very much thickened and deeply folded or conduplicate, thus appearing palmately lobed.




*Dacryodes edulis – 1, base of bole; 2, leaf; 3, leaflet; 4, inflorescence; 5, male flower in longitudinal section; 6, fruit; 7, endocarp; 8, seed.*
*Redrawn and adapted by W. Wessel-Brand.*

**Other botanical information** *Dacryodes* comprises about 40 species, occurring in the American, Asian and African tropics. In Africa, about 20 species have been found, all of section *Pachylobus*; Gabon seems richest with approximately 10 species. Several species have edible fruits.
*Dacryodes edulis* is very variable. Two varieties are recognized: var. *edulis* and var. *parvicarpa* J.C.Okafor, the latter being characterized by smaller conical fruits and thin pulp. Branching in var. *edulis* is often verticillate or subverticillate, in var. *parvicarpa* it tends to be opposite or bifurcate.

**Anatomy** Wood-anatomical description:
– Macroscopic characters:
Heartwood yellowish-pink, distinctly demarcated from the 2–4 cm wide, pale greyish-pink sapwood. Grain often interlocked. Texture moderately coarse. Growth rings indistinct.
– Microscopic characters:
Growth ring boundaries indistinct or absent. Vessels diffuse, 4–12/mm$^2$, solitary or in oblique or radial multiples of 2–3, tangential diameter (60–)135(–230) μm; perforation plates simple; intervessel pits alternate, 7–9 μm; thin-walled tyloses present. Ground tissue fibres septate, thin- to thick-walled, mean length 980 μm. Parenchyma rare, apotracheal parenchyma diffuse, indiscernible, paratracheal parenchyma irregularly unilateral. Rays narrow, (1–)2–3-seriate, 4–8/mm, mainly heterocellular with 1 or more rows of upright or square cells. Prismatic crystals in the marginal ray cells; silica bodies in the procumbent ray cells and small silica bodies in the fibres.

**Growth and development** Seed of *Dacryodes edulis* is recalcitrant; its germination rate drops sharply unless its water content (42% of fresh

weight) can be maintained. Unless sown within a week, germination and vigour are greatly reduced. Germination starts about 2 weeks after sowing and is epigeal. Early growth is vigorous. The seedling grows rhythmically, extending by flushes. During a flush, the leaf form changes abruptly from cataphylls (0–3 per flush) to normal leaves (with 11–19 leaflets). The flush is usually brought to an end by the sudden transition from normal leaves to severely reduced leaves in which only one or two basal pairs of leaflets are extended. Older trees flush infrequently. Branching normally is effected through shoots in the leaf axils of the last flush.

In adult trees, inflorescences may take the place of the axillary shoots, but often the entire shoot tip becomes floriferous, only the apical bud remaining vegetative and capable of producing another flush. The tree conforms to Rauh's architectural model: a monopodial architecture, orthotropic branching, and an endogenous growth rhythm characterized by alternating phases of active growth and rest.

The juvenile period lasts 4–6 years. Trees are either strictly male- or female-flowering. However, trees with hermaphrodite flowers associated with male flowers have also been reported. Whereas each tree flowers for about one month, the tree population blooms over a three-month period. Flowers open in the morning. Pollen is shed within 1–2 hours, so pollination has to be effected quickly. A strong perfume and agglutinate pollen facilitate pollination by insects, which are rewarded by nectar. About 80% of the visiting insects are bees. Pollination trials indicate that the viability of the pollen is excellent, that there are no problems with incompatibility, and that hand pollination does enhance fruit set but not the number of fruits at harvest. The fruit matures about 5 months after flowering.

**Ecology** The butter fruit tree is very adaptable, at home in evergreen rain forest, gallery forest and marshes. It grows from sea level to elevations of 1000 m, and from the high rainfall areas on the slopes of Mount Cameroon to monsoon areas that have 4 months with less than 50 mm/month of rainfall. The tree population flushes and flowers during the dry season. This means that flowering reaches a peak in January or February north of the equator, whereas south of the equator most trees flower in August or September. In coastal Gabon the flowers appear towards the end of the 3-month dry season, providing a cue that the planting season for field crops has started. However, near Bitam in northern Gabon the dry season lasts only 2 months, and this is too short to impose simultaneous flowering, and fruiting trees may be found at any time of the year. Much of the Gulf of Guinea region has a bimodal rainfall distribution and in some trees flowering is triggered by the short dry spell. For these reasons some fruit is harvested most of the year in several areas, but the main season is June to November north of the equator and December to April south of it. There is no information about soil types preferred by the crop, suggesting that soil requirements are not very exacting.

**Propagation and planting** The butter fruit tree is normally raised from seed, preferably freshly extracted from the fruit as viability declines rapidly when seed is stored. In the mature fruit the radicle has already emerged from the seed. Cloning is to be greatly preferred, not only to obtain plants of known sex, but also because the species is very variable. Vegetative propagation is difficult, but air layering has proved successful (up to 80% take) and is now practised in a few areas, using selected mother trees. It takes 4–6 months before the layers can be separated and this should not be done when the mother tree is about to flush. Plantlets have been obtained by tissue culturing of cotyledons. In laying out an orchard, 5% of the trees should be male-flowering to ensure adequate cross-pollination.

**Management** Care for the trees is minimal, often limited to slashing the weeds around each tree. Manures are not used except when planting; pruning and crop protection are not practised.

**Diseases and pests** In Gabon, 33 disease agents have been recorded on the butter fruit tree, mainly polyphagous fungi. The symptoms range from dieback of branches and leaf and fruit drop, to necrotic spots and galls on leaves and fruit. A study in Nigeria showed that 35–65% of the fruit were attacked by four post-harvest rots; *Botryodiplodia theobromae* and *Rhizopus stolonifer* were most important, accounting for 80% of the affected fruit; *Aspergillus niger* and an *Erwinia* bacterium being the other causal organisms.

A dipterous insect that mines the young leaves leads to continuous growth of the shoot because the leaflets drop before they mature. In Congo, the most important pest, leading to a burnt appearance of the leaves, is the caterpillar of *Sylepta baltoata*, a pyralid moth. In Cameroon, the larvae of a *Carpophilus* sp., a nitidulid beetle, eat the seed and when the adult bores its way out of the fruit secondary infections often lead to

decay. Much fruit is spoilt on the tree by birds.

**Harvesting** The fruit is ready for harvest when the colour changes, usually from pink to bluish. The seed is then also sufficiently mature to ensure maximum germination levels. Ripe fruit eventually drops but bruised fruit softens unevenly and decays quickly. Usually fruit is harvested by climbing the tree and beating the branches, or cut with the aid of a long pole fitted with a cutting device.

**Yield** Most farmers report yields of 20–50 kg of fruit per tree. A sample of 20-year-old trees yielded 110 kg per tree, far exceeding the yield of younger and older trees. For an orchard with 100–200 female-flowering trees per ha, annual yields of 10 t/ha or more appear feasible. There is no information on yield levels in areas where the growth rhythm is not synchronized, nor about biennial bearing.

**Handling after harvest** The fruit is gathered in baskets and taken to market. Packaging should be well ventilated, e.g. net bags or slotted crates. Post-harvest losses are large (locally exceeding 50% of the fruit) due to bruising during harvest and transport, and microbial rots.

**Genetic resources** The variability of the species has led to selection and cloning of superior trees for collections (Gabon, Cameroon) and for use as mother trees for propagation by air layers (Congo). However, no germplasm collections are known to be maintained.

**Prospects** There is a bright future for a fruit which is generally esteemed for its health benefits as well as its taste. More detailed knowledge of floral biology of this dioecious species, selection, and standardized vegetative propagation methods, are the main prerequisites for a breakthrough in productivity; more care in harvesting and handling will further increase the market value of the crop. Higher yields will also improve the economics of oil extraction, which – for a cottage industry – is already profitable at 10 t/ha. More attention for suitable applications of the wood seems justified.

**Major references** 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155

**Other references** 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2156, 2157, 2158, 2159, 2163

**Sources of illustration** 2146 (fruit), 2160 (leaflet, male flower in longitudinal section, endocarp, seed), 2161 (leaf, inflorescence), 2162 (base of bole)

**Authors** E.W.M. Verheij

## DACTYLADENIA BARTERI (Hook.f. ex Oliv.) Prance & F.White

**Protologue** Brittonia 31: 484 (1979).

**Family** Chrysobalanaceae

**Chromosome number** $2n = 22$

**Synonyms** *Griffonia barteri* Hook.f. ex Oliv. (1871), *Acioa barteri* (Hook.f. ex Oliv.) Engl. (1899).

**Vernacular names** Monkey fruit (En).

**Origin and geographic distribution** *Dactyladenia barteri* occurs naturally in West and Central Africa from Sierra Leone to Cameroon and Gabon. Its occurrence in Kivu in the Democratic Republic of Congo is uncertain.

**Uses** *Dactyladenia barteri* is widely used in south-eastern Nigeria as a fallow crop, producing large amounts of litter and recycling appreciable quantities of nutrients through its deep root system. The dense canopy also aids in weed suppression. In farmer's fields, it is either planted or protected in natural regrowth. Leaves are used for fodder. Stems provide good quality poles for staking crops and for construction work. The wood is used as fuel in Liberia. In Liberia, a liquor made from the bark is used as a purgative.

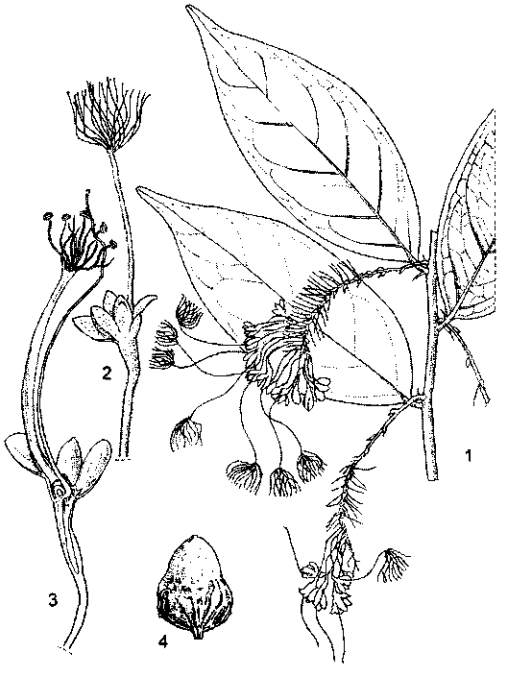
**Properties** The leaves of *Dactyladenia barteri* grown on acidic sandy soil contain per 100 g oven-dry matter: N 1.7 g, P 0.08 g, K 0.77 g, Ca 0.57 g, Mg 0.25 g, Cu 1.2 mg, Zn 0.8 mg. The leaves and probably also the bark are rich in tannin. The dark red wood is hard and durable and resistant to termite attack.

Prunings have a high C/N ratio (28:1–36:1), lignin (47.6%) and polyphenol (4.1%) content and decompose slowly in the soil, making good mulch material. The mulch has substantial effect on soil

*Dactyladenia barteri – wild.*

temperature, but little direct effect on soil nitrogen. Nitrogen immobilization by decomposing *Dactyladenia barteri* leaves is counteracted by increased mineralization of soil organic matter under the mulch. The decomposition rate of the mulch is very low (after 100 days as little as 20% may have decomposed, after 6 months about 50%).

**Description** Climbing shrub or small tree, up to 12 m tall; bole fluted, often multiple, crooked, up to 25(–40) cm in diameter; bark brittle, slash thin and watery-white, turning reddish; crown dense, spreading; young shoots dark red, covered with whitish, arachnoid tomentum, early caducous; branches more or less scandent, slender, hispid, very quickly glabrescent when young, with numerous lenticels when old. Leaves alternate, simple; stipules often attached near the base of the petiole, linear, 4–6 mm long; petiole 3–4 mm long; blade elliptical-oblong to ovate, 7–13(–15) cm × 3–5.5(–7) cm, base acuminate, sometimes broadly acuminate and somewhat asymmetrical, apex acuminate, dark glossy green, turning reddish-brown when senescent, lateral veins in 4–6 pairs, some circular glands often present on the underside of the blade near the base and the apex. Inflorescence a terminal or axillary raceme, single or sometimes in pairs, 3–4(–12) cm long, puberulous, many flowered; peduncle up to 1(–4) cm long; bracts elliptical-lanceolate, 2–4 mm long, tricuspidate, often with circular glands; flowers bisexual, zygomorphic; pedicel articulated, portion below articulation 6–10 mm long, long persistent, bearing 2 alternate, lanceolate bracteoles 1–1.5 mm long, upper portion 5–15 mm long; receptacle tubular, 4–6 mm long, puberulous; sepals 5, 4–5 mm long, puberulous outside; petals 5, oblong-obovoid, 4–5 mm long, white, caducous; stamens 15–20, (15–)25(–30) mm long, ligulately connate for most of their length, far exserted; pistil with 1-locular ovary, a filiform style slightly longer than the stamens, and a 3-lobed stigma. Fruit a single-seeded drupe, compressed-ovoid, 2.5 cm × 3.5 cm × 5.0 cm, green, surface often ferruginous-tomentose, apex often slightly tuberculate. Seedling with epigeal germination.




*Dactyladenia barteri – 1, flowering branch; 2, flower; 3, flower in longitudinal section; 4, fruit. Source: PROSEA.*

**Other botanical information** The genus *Dactyladenia* comprises about 27 species. It has been suggested that *Dactyladenia lehmbachii* (Engl.) Prance & F.White and *Dactyladenia pallescens* (Baill.) Prance & F.White, which flower in the same period, may cross-pollinate with *Dactyladenia barteri*.

**Growth and development** The root system is deep, but its lateral expansion in the top layer of the soil is limited. On an ultisol in south-eastern Nigeria, for instance, about 50% of the roots of less than 2 mm in diameter occurred in the top 20 cm of the soil near the stem, whereas at a distance of 120 cm from the tree base this percentage dropped sharply. In Nigeria and Ghana, *Dactyladenia barteri* usually flowers during the dry season, between October and February. Fruits mature at the beginning of the rainy season, between March and May. *Dactyladenia barteri* is open-pollinated, the main pollinators being red ants, but occasionally bees and wasps have been recorded.

**Ecology** *Dactyladenia barteri* occurs in lowland forest up to 300 m altitude with at least 1200 mm rainfall per year, where the mean minimum temperature of the coldest month is about 20°C and mean maximum temperature of the hottest month about 34°C. In the forest savanna transition zone, it is found along river banks. It occurs sometimes on the inland side of mangrove forest. It is well-adapted to leached, acid and infertile soils and can survive occasional flooding. Established trees are fire-resistant.

**Propagation and planting** Propagation is mainly by seed. Seed germinates readily. It can

be stored for up to 6 months at 15°C when treated with copper sulphate. Direct sowing is possible, but seedlings survive better when raised in nursery bags before planting out. Occasionally, stakes are used as cuttings in live fence systems. Juvenile stem cuttings will also root quickly at the peak of the rainy season.

**Management** In traditional cropping systems, *Dactyladenia barteri* is retained, planted scattered, or in hedgerows. Established trees coppice well, even after pollarding or burning. In south-eastern Nigeria it is planted in hedgerows in a traditional alley cropping system with inter-hedgerow spacing of 2–3 m and with 1–2 years of cropping followed by 3–4 years of fallow. Following the fallow period, the shrubs are underbrushed and burned and stems cut to a height of 10–20 cm. Some stems are left uncut for live staking of Guinea yam (*Dioscorea cayenensis* Lam.). Crops are then interplanted in the alleys.

**Yield** Planted at 4 m × 4 m spacing, *Dactyladenia barteri* can produce per ha 6 t dry prunings (leaves and small branches), 4 t twigs and 9 t wood within 8 months, with a nutrient yield of the prunings of 85 kg N, 5 kg P, 43 kg K, 18 kg Ca and 46 kg Mg. In an alley-cropping experiment, *Dactyladenia barteri* planted in rows 4 m apart at a within-row spacing of 50 cm produced 3.5 t/ha oven-dry litter and 1.4 t/ha dry wood when pruned 22 months after planting. The nutrient content of the prunings was: 65 kg N, 6 kg P, 41 kg K, 33 kg Ca and 13 kg Mg.

**Genetic resources** Provenance evaluation and variability studies are needed to reveal the amount of exploitable genetic variation which may exist within *Dactyladenia barteri*.

**Breeding** There is potential for genetic improvement of *Dactyladenia barteri* to enhance coppicing, growth and biomass yield.

**Prospects** *Dactyladenia barteri* has shown promise as a mulch and alley crop in experiments at the IITA (International Institute of Tropical Agriculture) in Nigeria. There is a need to evaluate its potential in other regions of the tropics with high rainfall and acid soils in agroforestry systems to promote sustained crop production on highly weathered soils. Already in use at the IITA as a test tree in alley cropping systems on poor acid soils, it may contribute to the development of such systems in other parts of Africa as well. *Dactyladenia barteri* has good prospects for fuelwood plantations as it coppices well.

**Major references** 5680, 5681, 5682, 5683, 5684, 5685, 5686

**Other references** 2054, 2109, 3795, 5687

**Sources of illustration** 3795

**Authors** D.O. Ladipo & B.T. Kang

## DIHETEROPOGON AMPLECTENS (Nees) Clayton

**Protologue** Kew Bull. 20: 75 (1966).

**Family** Poaceae (Gramineae)

**Chromosome number** $2n = 20, 40$

**Synonyms** *Andropogon amplectens* Nees (1841), *Andropogon diversifolius* Rendle (1899).

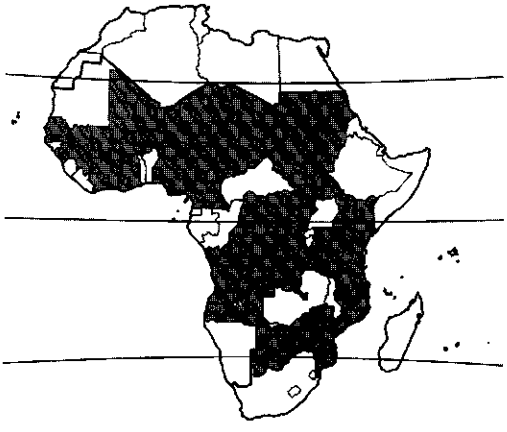
**Vernacular names** Broadleaf bluegrass (En).

**Origin and geographic distribution** *Diheteropogon amplectens* is widely distributed in Africa, from Senegal east to Sudan and Kenya, and south to Angola and South Africa.

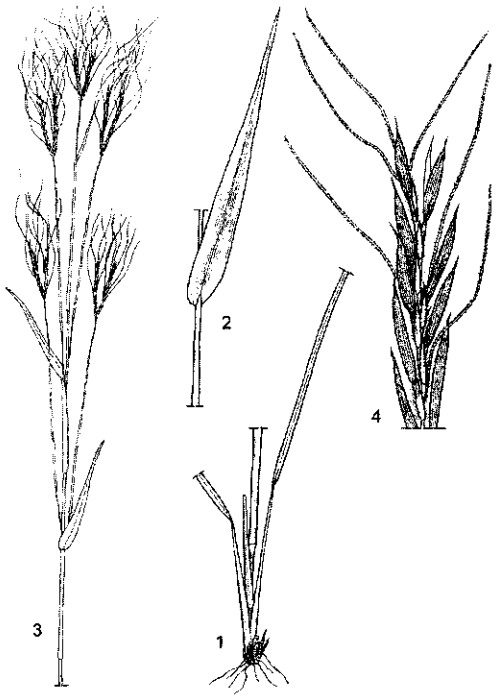
**Uses** *Diheteropogon amplectens* is an important forage species in permanent pastures grazed by ruminants. When still young, it is appreciated by all stock, and it makes an acceptable hay. Flowering plants are less willingly browsed because of the long, pungent awns. On sandy clay soils in Sudan, the vegetation co-dominated by *Diheteropogon amplectens* forms an excellent grass cover for cattle production because it is palatable and readily grazed. In Mozambique, the savanna vegetation with *Diheteropogon amplectens* has a varying grazing capacity; locally, the sparse cover has a carrying capacity of only 1 animal per 5 ha.

The culms are used for thatching and coarse matting.

**Description** Perennial herb up to 200 cm tall, growing in small tussocks, often with underground scaly shoots at base; culms cylindrical, with up to 9 nodes. Leaves alternate, simple; leaf sheath terete, tight, glabrous; ligule 1–1.5 mm



*Diheteropogon amplectens – wild.*




*Diheteropogon amplectens – 1, basal part of plant; 2, part of culm with leaf; 3, upper part of flowering plant; 4, part of inflorescence. Redrawn and adapted by M.M. Spitteler.*

long, truncate, membranous, glabrous; blade linear, 15–30 cm long, tapering into a filiform, glabrous to densely hairy, sharp tip, rough to almost smooth at margins; cauline leaves at base rounded-cordate or not and up to 20 mm wide. Inflorescence a paired raceme up to 9 cm long, up to 6 raceme pairs arranged into a scanty spathate false panicle. Spikelets paired, one sessile, the other pedicelled; sessile spikelet cylindrical, 2-flowered, lower floret reduced to a hyaline lemma, callus 1–2 mm long, pungent, lower glume 5–7 mm long, with 2 rounded, 4–7-veined keels, upper lemma 2-lobed at apex, with kneed, pubescent awn 2.5–7 cm long between the lobes; pedicelled spikelet larger, 9–13 mm long, male, often brownish or purplish, sometimes with an awn up to 8 mm long. Fruit a lanceolate caryopsis, hollowed on one face.

**Other botanical information** *Diheteropogon* comprises 5 species restricted to Africa. It belongs to the tribe *Andropogoneae*, subtribe *Andropogoninae*, together with e.g. *Andropogon*, having close links to sections *Piestium* and *Parahyparrhenia*. *Andropogon* differs in the callus of its sessile spikelet, which is obtuse and usually very short.

Two varieties are distinguished within *Diheteropogon amplectens*: var. *amplectens* occurring in eastern and southern Africa, which has most leaves basal and few linear, parallel-sided cauline leaves up to 7 mm wide at base, and var. *catangensis* (Chiov.) Clayton occurring over the whole range of the species, and which has most leaves cauline with a rounded-cordate base up to 20 mm wide. Intermediate forms are common.

**Growth and development** At the beginning of the rainy season culms with inflorescences develop out of a tussock. Flowering is at the end of the rainy season and beginning of the dry season. Regrowth, consisting of dry season basal leaves, takes place after burning in the dry season.

**Ecology** *Diheteropogon amplectens* occurs in grassland, often on shallow soils on stony hill slopes, and on poor sandy soils in savanna and deciduous bushland in areas receiving 900–1200 mm annual rainfall in western Africa, and 500–1500 mm/year in southern Africa. The altitudinal range is between 300 m in western Africa and 1800 m in eastern and southern Africa.

**Management** Annual fires maintain the vegetation type in which *Diheteropogon amplectens* occurs. In trials in Zimbabwe, the proportion of *Diheteropogon amplectens* in grass cover decreased by 17% after cattle grazing during several years (continuous and rotational) – a small reduction in comparison with that of other desirable grasses, such as *Hyperthelia dissoluta* (Steud.) Clayton (synonym: *Hyparrhenia dissoluta* (Nees ex Steud.) C.E.Hubb. ex Hutch. & Dalziel) and *Melinis repens* (Willd.) Zizka (synonym: *Rhynchelytrum repens* (Willd.) C.E.Hubb.). In a humid highland grassland in South Africa *Diheteropogon amplectens* was less common in grazed sites than in ungrazed ones. Application of N fertilizer decreased its proportion.

**Harvesting** The stems used for thatching and matting are collected at the beginning of the dry season, before they have dried out.

**Prospects** *Diheteropogon amplectens* has considerable local value as a forage. In the dry season it seems to be a valuable species with a good nutritional value, and reasonably capable of withstanding grazing pressure.

**Major references** 2106, 2133, 2135, 2136

**Other references** 2134, 2137

**Sources of illustration** 2133 (part of inflorescence), 2135 (basal part of plant, part of culm with leaf, upper part of flowering plant)

**Authors** A.P.M. van der Zon

**DIOSCOREA CAYENENSIS** Lam.

**Protologue** Encycl. 3(1): 233 (1789).
**Family** Dioscoreaceae
**Chromosome number** $2n = 36, 40, 54, 60, 66, 80, 140$
**Synonyms** *Dioscorea rotundata* Poir. (1813).
**Vernacular names** Guinea yam (En). Igname de Guinée (Fr). Inhame da Guiné (Po).

**Origin and geographic distribution** The Guinea yam group comprises *Dioscorea cayenensis* (yellow Guinea yam) and *Dioscorea rotundata* (white Guinea yam). Neither occurs in the wild. Guinea yam originated in West Africa, and occurs from Senegal to Ethiopia and Uganda. It probably arose in cultivation resulting from hybridization in the section *Enantiophyllum* of *Dioscorea*. *Dioscorea praehensilis* Benth., *Dioscorea abyssinica* Hochst. ex Kunth and *Dioscorea burkilliana* J.Miège are possible parents. Domestication still continues, e.g. in Benin where local farmers collect wild yam plants, and cross them with cultivated ones. Guinea yam is also planted in Central and East Africa, the Caribbean, Brazil and the Philippines. It has been introduced only very recently into Papua New Guinea and Oceania.

**Uses** Guinea yam is grown for its starchy underground tuber, which is the staple food in a belt from Côte d'Ivoire to Cameroon. This region accounts for over 95% of the world's cultivation of Guinea yam. The tuber is used almost exclusively for human consumption; only the peels are fed to animals. Unpeeled tubers may be boiled, roasted or baked; peeled tubers may be boiled or fried. A traditional method of preparation in West Africa is to pound the boiled peeled tuber to produce a thick dough (pounded yam). Pounded yam is consumed by rolling it into small balls which are then dipped into a sauce and swallowed (usually without chewing). Occasionally, the peeled tuber is cut into small chips, dried and then milled to produce yam flour. Chips may also be fermented before further processing. At meal time, the flour is stirred in boiling water and kneaded to produce a paste which is consumed in the same way as pounded yam. Industrial processes have resulted in the production of yam flakes which can be reconstituted in hot water to give a product similar to pounded yam or mashed yam.
In West Africa, Guinea yam has a high sociocultural value attached to its production and use. It is a prime object for traditional religious observances, social gift exchange, and cultural festivity. The start of its harvest even signifies the start of a new year. In these contexts, there is a strong preference for large tubers.

*Dioscorea cayenensis – planted.*

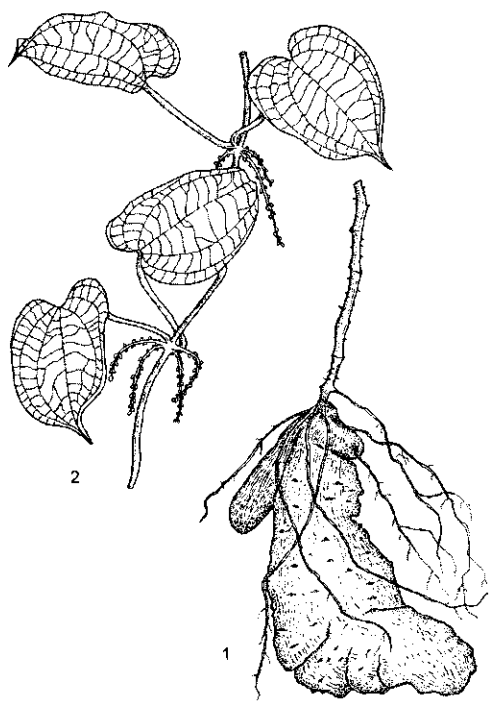
**Production and international trade** World production of all yams in 2000 was 38 million t grown on 3.9 million ha. Nearly 90% of this production came from the West African yam belt. Separate figures for Guinea yam are not available. However, given the fact that it is the predominant cultivated yam in West Africa, and that it is not extensively cultivated elsewhere, the production of Guinea yam in 2000 can be estimated at about 30 million t. Nigeria is by far the largest producer, followed in order by Ghana, Côte d'Ivoire and Benin. Virtually all production is by smallholders.
Small quantities of Guinea yam are exported from West Africa to Europe, and from the Caribbean to North America and Europe. However, the quantities are insignificant compared to total production.

**Properties** On a fresh weight basis, 100 g of tuber contains 58–80 g water, 15–23 g carbohydrate, 1–2 g crude protein, 0.05–0.12 g lipids, 0.35–0.79 g crude cellulose, and 0.68–2.56 g ash. Carbohydrates, predominantly starch (50–80%), comprise most of the dry matter. The starch granules of white Guinea yam are oval and measure 5–45 μm in diameter, whereas those of yellow Guinea yam are generally smaller and triangular. Starch granule size generally increases from the top of the tuber downwards, and from the subcutaneous region towards the centre. The protein content, though generally low, is highest close to the skin. Peeling therefore has to be done carefully in order to conserve as much of the protein as possible. The protein fraction is high in aspartic and glutamic acids, and low in

tryptophan and cystine. Some cultivars have significant amounts of vitamin C and thiamine. Freshly cut tubers cause skin irritation due to the presence of raphides, which are destroyed when the tubers are cooked. In some cultivars, the cut tuber is subject to oxidative browning or discoloration. Cooking immediately after peeling or cutting reduces the degree of discoloration.

**Adulterations and substitutes** Cassava products are often added as adulterants to pounded yam or yam flour because of the relative cheapness of cassava.

**Description** Dioecious, exceptionally monoecious, glabrous herb with annual twining stem arising from tuber; tuber usually solitary, cylindrical to irregularly shaped, up to 10(–25) kg in weight, flesh whitish or yellowish, with or without prickly superficial roots, giving rise to 1 or few annually renewed tubercules; stem up to 12 m long, twining to the right, glabrous, spiny or not. Leaves usually alternate in basal part of stem and opposite in upper part, basal leaves often strongly reduced, simple; stipules absent; petiole 5–12 cm long; blade broadly ovate to suborbicular, 5.5–12 cm × 5–10 cm, broadly cordate at base, acuminate at apex, entire, 5–7-veined. Inflorescence an axillary unisexual spike, male 1–3 together and 4–6 cm long, female 1–2 together and 10–12 cm long. Flowers unisexual, regular, with 6-lobed perianth; male flowers small (1–2 mm in diameter), sessile or shortly pedicelled, with 6 stamens; female flowers with inferior, 3-celled ovary, styles 3, short. Fruit a capsule wider than long, 2–2.5 cm × 3–3.5 cm, opening by 3 valves, up to 6-seeded. Seeds 1–1.5 cm × 1–1.5 cm, with large circular wing.




*Dioscorea cayenensis – 1, tuber; 2, part of stem with male inflorescences.*
*Redrawn and adapted by W. Wessel-Brand.*

**Other botanical information** It is still not clear whether *Dioscorea cayenensis* and *Dioscorea rotundata* represent different taxa, or are the same. In the botanical literature, the latter is often considered a synonym of the former. However, two distinct groups are recognized in agronomical practice: yellow Guinea yam and white Guinea yam, broadly corresponding to *Dioscorea cayenensis* and *Dioscorea rotundata*, respectively. The tuber flesh is yellow in *Dioscorea cayenensis* and white in *Dioscorea rotundata*, but intermediate cultivars are common. Molecular marker-based taxonomy supports the view of 2 different taxa. Both are only known from cultivation, and it would be appropriate to treat them as cultivar-groups.

Numerous (possibly 2500) named and unnamed cultivars exist, characterized by leaf shape, tuber shape, size and colour, stem colour, degree of spinescence of stems and roots and ecological requirements.

**Growth and development** Four growth phases have been recognized in white Guinea yam grown from tubers. The first phase lasts for 6 weeks from emergence. It includes root proliferation and extensive vine elongation, but very little leaf expansion. Growth during this phase is dependent on food stored in the parent tuber. The second phase lasts from 6–10 weeks after emergence and is marked by strong leaf expansion and transition to full autotrophy. Tuber initiation occurs towards the end of this phase. The third phase lasts from 10–18 weeks after emergence and includes tuber bulking. The leaf area and vine length do not increase much during this phase, and the quantity of living roots decreases. The fourth phase lasts from 18 weeks after emergence till leaf, vine and root senescence at the end of the season, 6–7 months after emergence. The resulting tuber (whether harvested or left in the ground) remains dormant for 2–3 months before it begins to sprout.

Flowering is irregular, but commences late in the second phase or early in the third phase in cultivars that do flower. Fruit and seed produc-

tion are uncommon. The seeds have a dormancy of 3–4 months after the senescence of aerial parts of the plant. Seedlings are less vigorous than plantlets raised from tuber 'sets', but generally go through the same four growth phases.
Yellow Guinea yam requires a growing period of 10–12 months. The tuber has only a short dormancy period.

**Ecology** Guinea yam requires a temperature of 25–30°C for normal growth; therefore it is strictly tropical. Vine growth is severely limited below 20°C, while soil temperature above 35°C retards sprouting of planted sets. White Guinea yam is better adapted to savanna regions with their longer dry season, while yellow Guinea yam is cultivated in the West African forest zone, where the dry season is comparatively short and the growing season lasts about 11 months. In white Guinea yam, water supply must be adequate for the 6–7 months of the plant's growth phases. Evenly distributed rainfall of 1500 mm/year is optimal, but small crops can be obtained with as little as 600 mm/year. At such low rainfall, however, production of seed tubers is low. Drought tolerance is best during sprouting and the first growth phase. Drought stress during later phases results in leaf abscission and subsequent reduction in tuber yield.
Guinea yam performs poorly unless the soil is very fertile. Mycorrhizal associations promote phosphorus uptake in soils that are phosphorus-deficient. Nitrogen and potassium deficiencies are frequently encountered. Optimum pH is 5.5–6.5. Aluminium toxicity is a problem at pH less than 5.5. The soil must be well drained to at least 90 cm depth. The soil should be free of coarse gravel or stones, and devoid of a hard pan, otherwise tuber shape is distorted. Low light intensity decreases the tuber/vine ratio, and results in low yields.

**Propagation and planting** Propagation is normally by tubers. Up to 20% of the yield of Guinea yam is set aside as planting material. The best planting material is a small intact tuber (or 'set') 100–500 g in fresh weight. For sets derived by cutting up large tubers, the head set is preferable to middle or tail sets. Intact tubers or head sets sprout from buds present in the primary nodal complex. Middle or tail sets (or heads with the nodal complex removed) sprout *de novo* through meristematic activity beneath the skin. Generally, sets that sprout readily from cultivars that are resistant to post-planting rotting or degradation are preferred.
Freshly-harvested tubers of white Guinea yam are dormant for 2–3 months before they sprout. The longer a tuber has been stored after harvest, the more rapidly budless sets derived from it will sprout. However, even for long-stored tubers, the minimum time for sprout formation in budless sets taken from them is 3 weeks. Under field conditions, time from planting to emergence is 1–3 months. Emergence in a given field is scattered over a long period of time; thus the uniformity of emergence is low.
The weight of the parent sets profoundly affects the growth and performance of plants raised from tubers. The larger the set, the more vigorously it sprouts, the greater the resultant leaf area, the earlier the tuber development, and the larger the tuber produced. However, large sets result in a low multiplication ratio. The planting of very small sets (called 'minisets', 15–50 g each) to produce tubers for subsequent commercial planting is extensively practised.
Planting is on mounds 30–60 cm high, or on ridges. Spacing is 1 m × 1 m. Sets are inserted 10–15 cm deep. Intercropping is the most frequent practice, but sole-cropping is also common.
Propagation by seed is possible, but uneconomic. Seed production is irregular; some cultivars do not set seed. There is a dormancy period of 3–4 months prior to germination. Seedlings are weak and require careful attention in the nursery. The tuber yield of plants propagated by seed is very small. Propagation by tissue culture is also possible, but as with seed propagation, the resulting tuber is extremely small. Propagation by seed and tissue culture is, therefore, essentially a research tool, and for rapid multiplication of disease-free cultivars.

**Management** Mulching is often necessary to protect sets from excessive heat between planting and emergence. At 1–2 months after emergence, stakes 1–2 m long are installed. Plants may be staked individually, or several plants may be trained on to one large stake. Pollarded shrubs (live stakes), left after clearing, may also serve as stakes. Staking is a very labour-intensive operation, and is most critical in high-rainfall regions and in forest regions where plants are shaded and where staking materials are abundant. In savanna regions, adequate yields are obtained without staking.
The critical period for weed control is the first 1–3 months after emergence. Weeding 2–3 times during the season with hand tools is the general practice. Herbicides such as diuron and ametryne are sometimes used.
The crop responds well to nitrogen and potassium

fertilizers; it responds less well to phosphorus applications, possibly because mycorrhizal associations make sufficient soil phosphorus available. Compound NPK fertilizers of various formulations are in use. Split application of the fertilizer is recommended, with the first application 1 month after emergence (in the first growth phase) and the second application 3 months after emergence, during tuber bulking (the third growth phase). Most traditional farmers avoid use of chemical fertilizers in the belief that they reduce the storability of the resulting tubers.

**Diseases and pests** Storage and tuber rots, caused by *Penicillium*, *Fusarium* and *Botryodiplodia* species, are responsible for high post-harvest losses. Guinea yam is relatively resistant to yam anthracnose (caused by *Colletotrichum* and *Glomerella*), which is so devastating in greater yam (*Dioscorea alata* L.).

The yam beetle (*Heteroligus* sp.) is a major pest. Adults migrate into yam plots in mid-season, burrow into the base of the plant, and begin feeding on the enlarging tubers, causing hemispherical holes which render harvested tubers unmarketable and predisposed to rotting. At end of the season, the adult beetles mate and migrate to swampy areas to lay their eggs. Larval and pupal stages are spent in these locations, until the resulting adult beetle emerges early in the rainy season, ready to migrate to yam plots. Yam beetle is controlled with insecticides or by planting very late.

Yam nematode (*Scutellonema bradys*) and root-knot nematode (*Meloidogyne* sp.) occur in some locations. They cause damage to the meristem of the tuber, and result in a warty appearance of the tuber. The main control measure is crop rotation.

A virus complex is reportedly endemic in the yam belt, and may be responsible for the generally low yields. Thermotherapy and meristem culture have been used to produce virus-free materials for distribution.

**Harvesting** White Guinea yam is harvested 6–8 months after emergence; yellow Guinea yam after about 12 months. The signal for harvesting is the senescence of the shoot. Harvesting is invariably done with hand tools.

Double-harvesting of the same plants is sometimes practised in white Guinea yam. This involves a first harvest 4–5 months after emergence, during which the tuber is carefully removed with minimum damage to the roots and the rest of the plant. This is followed 2–3 months later by a second harvest of the same plants, after shoot senescence. The first harvest supplies new yams for food early in the season, although the tubers have a high water content. The second harvest yields excellent planting material since the tubers possess numerous buds and are less prone to rotting.

**Yield** Average yield in tropical Africa is about 10 t/ha of fresh tubers. Typical yields in 1999 were 12.7 t/ha for Ghana, 11.1 t/ha for Benin, 10.8 t/ha for Côte d'Ivoire, and 9.6 t/ha for Nigeria. In experiments, yields of 60 t/ha have been obtained.

**Handling after harvest** Traditionally, the harvested tubers are collected from the field, and then tied up in a yam barn, which is essentially a framework of vertical wooden poles. The barn is usually constructed in the open, either on the farm or behind the home. When the next rainy season sets in, the tubers are usually moved indoors and stored on a platform.

It is essential that the tubers are well aerated during storage, and frequently inspected for rotting or sprouting, and kept as cool as possible. However, temperatures below 15°C cause the tuber to darken and deteriorate. This, in addition to the cost of refrigeration, makes refrigerated cold storage unfeasible.

Virtually all harvested tubers are stored and marketed whole. Only a very small quantity is used to make yam flour (from dry yam chips), or yam flakes.

**Genetic resources** Field collections of Guinea yam occur in various parts of tropical Africa and elsewhere in the world. Significant collections are maintained in Côte d'Ivoire (University), IITA (International Institute of Tropical Agriculture) in Ibadan, Nigeria, the National Root Crops Research Institute at Umudike, Nigeria, at various agricultural research stations in the western part of Cameroon, and at Mayagüez in Puerto Rico. A great deal of genetic diversity exists and is maintained on farmer's fields. Significant *in vitro* collections exist at the IITA in Nigeria, as well as at IRD (Institut de Recherche pour le Développement) in Montpellier, France. Much of this has been characterized and indexed for the yam mosaic virus.

**Breeding** The main breeding objectives include: 1) yield improvement; 2) production of more rounded (as opposed to cylindrical) tubers that are easier to harvest and handle; 3) improved flavour, texture and protein content of the tuber; 4) production of disease and pest tolerant cultivars; and 5) the improvement of plant architecture so as to eliminate the need for staking. Most of the crop improvement effort to date has concentrated on selecting from the very broad

genetic diversity that already exists in farmer's fields. This activity is carried out at the various centres where collections are kept. Some DNA fingerprinting work has been carried out at IITA.

**Prospects** The main constraints to production are very high labour requirements, low yields, storage problems and the large quantity of planting material needed. These factors give rise to poor production economics and a high unit cost of tubers reaching the table. Genetic engineering may help by introducing desirable characteristics into the crop. Declining soil fertility and poor production economics will progressively give the competitive edge to more resilient crops, especially cassava. However, the socio-cultural significance of Guinea yam in tropical Africa will ensure its production and value.

**Major references** 2105, 5695, 5698, 5699, 5700, 5701, 5702, 5703, 5704, 5705

**Other references** 5695, 5696, 5706, 5707, 5708, 5709, 5710, 5711, 5712, 5713, 5714, 5715, 5716

**Sources of illustration** 5695

**Authors** I. C. Onwueme & P. Hamon

## DODONAEA VISCOSA Jacq.

**Protologue** Enum. syst. pl.: 19 (1760).

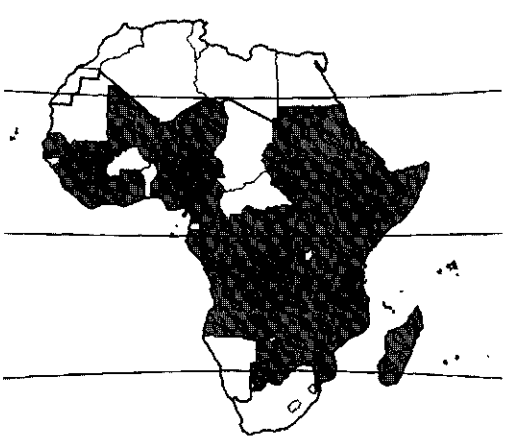
**Family** Sapindaceae

**Chromosome number** $2n = 28$

**Synonyms** *Dodonaea angustifolia* L.f. (1782).

**Vernacular names** Hopbush, switch sorrel, sand olive (En). Dodonée visqueuse (Fr). Vassoura vermelha (Po). Mkaa pwani, mkengata (Sw)

**Origin and geographic distribution** The centre of origin of *Dodonaea viscosa* is believed to be Australia, but it occurs throughout the tropics and subtropics. Outside Australia, two varieties have been recognized: var. *viscosa*, which in Africa occurs naturally along the coasts of West Africa (from Senegal to Nigeria) and East Africa (from Kenya to Mozambique), and in Madagascar; and var. *angustifolia* (L.f.) Benth., which occurs naturally from the Democratic Republic of Congo in the west to Ethiopia and Somalia in the east, and South Africa in the south, and also in Madagascar. The latter variety is cultivated in Ghana, Nigeria and Cameroon. Both varieties are pantropical.



*Dodonaea viscosa – wild.*

*Dodonaea viscosa* is not an obvious plant for deliberate planting, but its widespread range and similar patterns of uses in different countries may be partly explained through human distribution.

**Uses** *Dodonaea viscosa* has many uses. It is a traditional medicine worldwide, administered orally or as poultice to treat a great variety of ailments. Stem or leaf infusions are used to treat sore throats; root infusions to treat colds. The stems and leaves are used to treat fever, and seeds (in combination with those of other plants and coated in honey) to treat malaria. The stems are used as fumigants to treat rheumatism. The leaves are used to relieve itching, and a lotion made from unspecified plant parts to treat sprains, bruises, burns and wounds. Digestive system disorders, including indigestion, ulcers, diarrhoea and constipation are commonly treated in traditional medicine with an orally-administered decoction of either the leaves or roots. Trachoma is treated with applications of leaf juice, and powdered leaves are given to expel roundworms. Pulverized roots are a component of anthelmintic preparations. The roots, either in decoction or fresh, are taken by women in East Africa to stimulate milk production after giving birth and to treat dysmenorrhoea and irregular menstruation. In Ethiopia women make an amulet of *Dodonaea viscosa* and other plants wrapped in red silk thread and worn around the thigh to ward off infertility.

The wood of *Dodonaea viscosa* is used for tool handles, tools, brooms, digging sticks, spears, clubs and poles; when available in large sizes, also for posts and frames for permanent structures and in Kenya to make ribs of dhows. Throughout its range *Dodonaea viscosa* is an important source of fuelwood; in East Africa it is favoured for the production of charcoal. In some areas twigs are used as toothbrushes.

*Dodonaea viscosa* is used in reforestation, reclamation of marshes and degraded land, and as a

soil stabilizer. It makes a good live fence for dry areas and is planted as a windbreak. It is commonly cultivated as an ornamental throughout its range on account of its abundant fruiting and glossy leaves. Cultivars with leaves ranging from bluish-red, pink and red to yellowish-green have been developed. The leaves and fruits are also used in making garlands. It makes a sturdy hedge that withstands clipping and is amenable to topiary work.

In tropical Africa *Dodonaea viscosa* is browsed by livestock and camels and used as an emergency fodder during the dry season. It is a source of nectar and pollen for honey. The seeds yield a fish poison.

Other uses include stuffing and binding mattresses in Peru using stem-fibre and leaf-resin, while in Papua New Guinea leaves are packed into walls of houses for insulation. In Australia the tannin from the bark is used for tanning skins; the bark is, however, considered to be a tanning material of inferior quality. The fruits are used in pot-pourri and, in the past, they have been used as a substitute for hops in yeast production and beer making in Iraq and Australia.

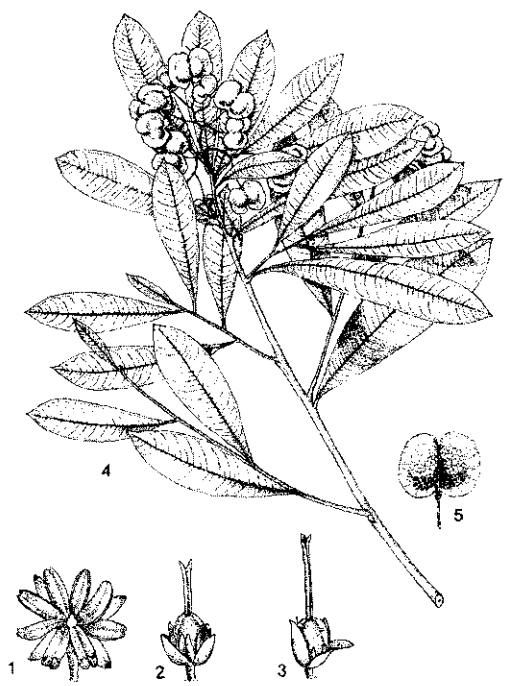
**Production and international trade** *Dodonaea viscosa* is mainly grown or collected for domestic or local use, but the leaves are sold in local markets for medicinal purposes in South Africa and Mexico.

**Properties** The use of *Dodonaea viscosa* in traditional medicine is reflected, in some instances, in the plant's pharmacological properties. Essential oils and extracts obtained from the leaves exhibited antibacterial and hypotensive activities. Aqueous and alcoholic extracts were found to exhibit cardiac depressant and coronary-constricting properties, and slight anthelmintic activity. A saponin mixture from the seeds has been shown to have phagocytosis enhancing, analgesic and molluscicidal (including against the schistosomiasis-transferring snail *Biomphalaria glabrata*) properties. The use of the seeds as a fish poison is supported by the presence of triterpene saponins.

A number of 3-methoxy flavones derived from quercetin and kaempferol in the seeds, bark, inflorescences and leaves exhibited pronounced antiviral activity and were active in tissue cultures against polio-, rhino- and picorna-viruses. Spasmolytic activity could arise from the presence of some diterpenes, sakuranetin, quercetin and rutin in the seeds, bark, inflorescences and leaves. A chloroform-methanol extract from aerial parts was found to inhibit the spontaneous contraction of the intestinal smooth muscle of isolated rat and guinea-pig ileum in a concentration-dependent manner. This could explain the use of *Dodonaea viscosa* preparations to alleviate gastrointestinal disorders. The isolated coumarin fraxetin has attracted some attention as an anti-oxidant, and it displayed analgesic properties in tests with mice. In addition, various extracts of *Dodonaea viscosa* showed insecticidal activity against the cotton leafworm *Spodoptera littoralis*.

The wood is extremely hard and close grained; it makes a good fuelwood as it can be easily ignited and is slow and hot to burn. The energy value is about 19,225 kJ/kg. The wood is resinous and flexible, though tough and rather laborious to chop; it is fairly resistant to termite attack. The heartwood is dark brown, with an irregular outline, sometimes mottled with black. The sapwood is pale. The wood is very heavy, 1200–1250 kg/m$^3$.

**Description** Dioecious or monoecious multi-stemmed shrub or single-stemmed small tree up to 7(–9) m tall; bole up to 20 cm in diameter; bark blackish, of variable roughness, thin and exfoliating in long thin strips; twigs blackish or reddish-




*Dodonaea viscosa – 1, male flower; 2, bisexual flower; 3, female flower; 4, fruiting twig; 5, fruit. Source: PROSEA.*

brown, glandular, developing vertical fissures, uppermost part of young branches greenish and prominently angled. Leaves alternate, simple; stipules absent; petiole very short, up to 2.5 mm long, or absent; blade oblanceolate or broadly to narrowly elliptical, (1–)4–13 cm × (0.5–)1.5–4 cm, narrowly cuneate at base, obtuse but minutely apiculate at apex, margins entire, both surfaces glabrous but glandular and coated (especially when young) with viscid glandular exudate, with a conspicuous midrib on both sides and 15–20-(–30) often indistinct pairs of lateral veins. Inflorescence a loose thyrsoid panicle at the end of twigs. Flowers bisexual or unisexual, whitish to greenish-yellow; pedicel 8–15 mm long; sepals 3–4, free, 2–2.5 mm long; petals absent; stamens 7(–9), filaments very short, anthers oblong, up to 3 mm long in male flowers, up to 2 mm long in bisexual flowers and reduced to staminodes or completely lacking in female flowers; ovary superior, oblong in outline, flattened, 2–3-celled, strongly rudimentary in male flowers, style 2–3-lobed. Fruit a 2–3-winged papery capsule, 15–23 mm × 18–25 mm, white or straw-coloured to brown or purplish, dehiscent by splitting along 2–3 central septa, each cell 2-seeded. Seeds subglobose, more or less compressed, ca. 3 mm in diameter, black. Seedling with epigeal germination; hypocotyl 8–16 mm long; cotyledons lanceolate, acute; epicotyl 0.5–1.5 cm long.

**Other botanical information** The genus *Dodonaea* comprises about 60 species, which are almost all restricted to Australia, suggesting Australia is an evolutionary centre of dispersal. In Australia, *Dodonaea viscosa* is described as having seven subspecies, which are largely geographically distinct. In tropical Africa, 2 varieties of *Dodonaea viscosa* are distinguished: the coastal var. *viscosa*, which has usually bisexual, whitish flowers, a strongly 2-lobed scar of fallen sepals beneath the fruit and not or only slightly compressed seeds, and the mainly inland var. *angustifolia* (L.f.) Benth., which has usually shorter and narrower leaves, usually unisexual, greenish-yellow flowers, a more or less annular scar of fallen sepals beneath the fruit and more compressed seeds. These differences are sometimes considered sufficient to distinguish 2 separate species, the latter variety given specific rank (as *Dodonaea angustifolia* L.f.).

**Growth and development** *Dodonaea viscosa* produces large quantities of seed at an early age. It is capable of flowering and setting viable seed within three years of establishment. The number of seeds per kg is about 100,000. The mean germination of seed will be greater than 75% under optimal conditions. In East Africa the germination rate is recorded as 30–70% after 15 days. Flowering occurs almost all the year round throughout its geographical range, but most populations flower in spring and summer. Pollination is probably by wind, although bees have been observed to collect pollen. The fruits take 10–11 months to mature after flowering. They are broad winged, giving the impression of being dispersed by wind.

**Ecology** *Dodonaea viscosa* var. *viscosa* occurs in coastal bushland, on the landward side of mangrove forest, on sand dunes and coral rock mostly just above the high water mark. In East Africa it is also found in *Casuarina* woodland, *Grewia glandulosa* Vahl scrubland and plantations up to an altitude of 75 m. Var. *angustifolia* occurs in grassland, bushland, woodland or forest on lava, often in rocky places, stony hillsides and disturbed areas up to 2700 m, generally above 1000 m. *Dodonaea viscosa* is a pioneer species that will readily colonize open areas, abandoned gardens or secondary forest. It is tolerant of salinity, drought, strong winds and pollution.

**Propagation and planting** *Dodonaea viscosa* regenerates profusely by seed, germination being enhanced by both fire and soil disturbance. The seeds are desiccation tolerant and maintain high levels of viability for long periods when dry. Pretreatment of the seed by scarification, nicking the seed coat, or with boiling water promotes germination. Rains must follow germination to ensure seedling survival. Plantations can be established by direct sowing or by using nursery-raised seedlings. Propagation by stem cuttings has been practised successfully.

**Management** *Dodonaea viscosa* is rarely cultivated except as a garden plant. Mature plants are fast growing and require little or no management once established. They can resprout from the stem base and recover well after cutting and light fires. However, their ability to regenerate from underground stems is not well developed. Furthermore, juvenile plants are more susceptible to damage by fire than older shrubs. For ornamental purposes shrubs are pruned to improve their appearance; cutting into old wood should be avoided.

**Diseases and pests** Dodonaea yellow disease, a disease similar to the 'spike' disease of sandalwood (*Santalum album* L.) affects *Dodonaea viscosa*. It is probably caused by phytoplasma-like organisms. Diseased plants have a bushy appearance with smaller leaves reminiscent of witches'

broom, and flowering and fruiting cease. If severely infected the plants die. Several diseases are of local importance, such as leaf blight, leaf spot disease and powdery mildew. *Dodonaea viscosa* is a host of the root-knot nematode *Meloidogyne incognita*, which can affect many cultivated crops. In India, *Dodonaea viscosa* is affected by the castor semi-looper (*Achaea janata*), which also affects *Ricinus communis* L. and fruit trees such as *Citrus*. In South Africa, the tree is often infested with a white scale, and in South Australia leaves and branches are damaged by a gall midge.

**Harvesting** Fruits, leaves, bark and wood of *Dodonaea viscosa* are collected whenever the need arises.

**Genetic resources** *Dodonaea viscosa* is common and extremely widespread and not threatened. It is represented in some seedbank collections, and selections for ornamental purposes are sometimes marketed.

**Prospects** The potential of *Dodonaea viscosa* in medicine requires further research, especially with regard to its pharmacological properties. A number of compounds (e.g. fraxetin, sakuranetin and some diterpenes) may provide interesting leads for pharmacological evaluation and therefore merit further research. The ability to regenerate quickly in poor soils makes this species suitable for reclaiming denuded land. There is also potential to increase its use as a fuelwood. Indeed, in Uganda, it has been recommended for planting for firewood in the highlands of Kabale where it would also be useful in stabilizing soil-conservation structures. The ability of the timber to resist termite attack makes *Dodonaea viscosa* potentially important for use in constructions in tropical Africa.

**Major references** 2108, 3899, 4754, 5744, 5745, 5746, 5747, 5748, 5749

**Other references** 3807, 5750, 5751, 5752, 5753, 5754, 5755, 5756, 5757, 5758, 5759, 5760, 5761, 5762, 5763, 5764

**Sources of illustration** 3797

**Authors** G. Pearman

## ENSETE VENTRICOSUM (Welw.) Cheesman

**Protologue** Kew Bull. 1947(2): 101 (1948).

**Family** Musaceae

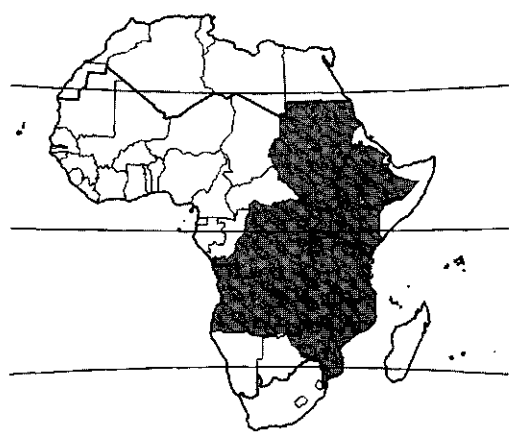
**Chromosome number** $2n = 18$

**Synonyms** *Musa ensete* J.F.Gmel. (1791), *Musa ventricosa* Welw. (1859), *Ensete edule* Bruce ex Horan. (1862).

**Vernacular names** Enset, false banana (En). Ensète, bananier d'Abyssinie (Fr).

**Origin and geographic distribution** The wild form of *Ensete ventricosum* is widespread in tropical Africa from Ethiopia, through Kenya, Uganda and Tanzania south to Mozambique and South Africa (Transvaal), and west to the Democratic Republic of Congo. Enset is cultivated only in Ethiopia, where it was first domesticated possibly about 8000 years ago. The centre of enset cultivation is in the mountains of south-western Ethiopia.

**Uses** Enset is the main food for 7–10 million people in the highlands of south and south-western Ethiopia. These regions are among the most densely populated in the whole of Ethiopia and are inhabited by more than 11 ethnic groups, which show great variation in culture and agricultural practices. Enset is primarily grown to produce a starchy food from the pseudostem, corm and stalk of the inflorescence. The mixture of scraped pseudostem pulp and the pulverized corm and stalk of the inflorescence is put into a pit for fermentation and the resulting product is locally called 'kocho'. 'Bulla' is prepared from the starchy liquid obtained by squeezing the mixture. The solid parts can be consumed after they are allowed to settle for some days. Both kocho and bulla are mostly made into a dough that is rolled out into a thin layer and baked on a hotplate over an open fire. In some enset-growing areas, kocho is a prestige food kept for feasts and ceremonies. At weddings, a leavened bread made from kocho and wheat flour is sometimes served. Bulla is also eaten as a porridge. The enset corm is eaten as 'amicho', i.e. cooked fresh and consumed in a way similar to potato, sweet potato or cassava.



*Ensete ventricosum – wild.*

The leaf sheaths of *Ensete ventricosum* provide good quality fibre for making rope, twine, baskets, suitcases, mats and sacks. The dried leaf sheaths are used as packing and wrapping material, in fences, mattresses, mats and in house construction. Fresh leaves provide shade in nurseries. The entire plant or parts of it, except the roots, are used to feed livestock. Ethiopian people believe that particular *Ensete ventricosum* landraces have various medicinal properties. Enset is used to treat broken bones. A decoction of pounded leaves is taken to stimulate labour or induce abortion. Hepatitis and other liver complaints are treated with ash and infusions from the fruit and leaves. Enset landraces with peculiar leaf and pseudostem colour are grown worldwide for ornamental purposes.

Outside Ethiopia use of *Ensete* is only reported from Vietnam, where it provided an emergency food during the Second World War. In parts of north and central Vietnam the growing point is used as a vegetable.

**Production and international trade** *Ensete ventricosum* is economically important only in Ethiopia. Ethiopian statistics indicate that there are 167,900 ha of enset. In 1997 about 3.28 million t of kocho and 0.12 million t bulla were produced. An average family, dependent on enset as a major food crop, cultivates 200–400 plants, and the yearly consumption per person averages from 10 to 20 plants.

**Properties** The main feature of enset foods is their high energy value (1410–1950 kJ per 100 g dry matter of kocho, 1580–1850 kJ per 100 g dry matter of bulla), derived almost entirely from carbohydrates. Fresh kocho contains 47–62 g moisture per 100 g. Per 100 g dry matter the approximate composition of kocho is: protein 1.1–2.8 g, fat 0.2–0.5 g, carbohydrates 95–98 g, fibre 2.3–6.2 g, ash 1.7 g, Ca 60 mg, P 68 mg, Fe 7 mg, thiamine 0.06 mg, riboflavin 0.08 mg, niacin 0.6 mg. The moisture content of bulla ranges from 44–55 g per 100 g fresh material. Per 100 g dry matter the approximate composition of bulla is: protein 0.4–0.8(–1.9) g, fat 0.2–0.4 g, carbohydrates 93–98 g, fibre 0.6–0.8 g, ash 0.2 g, Ca 91 mg, P 44 mg, Fe 5.8 mg, thiamine 0.02 mg, niacin 0.2 mg.

Little is known about fibre quality. Its strength of about 50 g/denier is somewhat greater than sisal but less than abaca.

Feed value of whole enset plants is higher than that of many crop by-products. The leaves contain on average per 100 g dry matter about 12 g crude protein, 63 g neutral detergent fibre (NDF), 41 g acid detergent fibre (ADF), 7 g lignin and 13 g ash; the pseudostem contains on average 7 g crude protein, 24 g NDF, 10 g ADF, 2 g lignin and 8 g ash.

**Description** Monocarpic, perennial giant herb 4–8(–11) m tall, with pseudostem formed of overlapping leaf sheaths, swollen at the base, the underground portion consisting of a corm 0.7–1.8 m long, with circumference 1.5–2.5 m at maturity; root system usually adventitious. Leaves arranged spirally, arising from the apex of the corm, with elongated leaf sheaths; lamina oblong to oblanceolate-oblong, up to 5 m × 1.5 m, entire, with strongly channelled midrib and many parallel lateral veins, bright to dark green, midrib, petiole and margin sometimes pale to dark red or dark purple, rarely the lower side reddish. Inflorescence a terminal thyrse growing up through the centre of the pseudostem and thus appearing to arise from its apex, bearing cincinnate flower clusters in axils of spathaceous bracts on an indeterminate main axis, exserted part of inflorescence commonly 1–2 m long, drooping. Flowers unisexual, zygomorphic, functionally female ones on the proximal part of the inflorescence, male ones on the distal part;


*Ensete ventricosum – 1, habit of flowering plant; 2, inflorescence; 3, fruit; 4, seed.*
*Redrawn and adapted by M.M. Spitteler.*

male flowers with one 3-lobed outer tepal up to 5.5 cm long, white with orange-yellow tips, one serrate-apiculate inner tepal, 5 up to 5 cm long stamens having violet to purple anthers, sometimes also with a staminode up to 1 cm long, and a slender style up to 2 cm long; female flowers with one deeply 3-lobed outer tepal up to 5.5 cm long, 1–3 inner tepals variable in shape with 2 wings and an apiculum up to 1.5 cm long, 0–5 more or less rudimentary stamens, and an inferior, 3-celled ovary bearing a style 2.5–4 cm long, with a large capitate stigma. Fruit an oblong-obovoid berry, 8–15 cm × 3–4.5 cm, orange when mature, rather dry, fibrous, 1–10-seeded. Seeds irregularly subglobose, about 1.5–2.5 cm in diameter, black.

**Other botanical information** The genus *Ensete* comprises about 7 species, 3 in tropical Africa, 1 in Madagascar and 3 in tropical Asia. Among the African species, *Ensete gillettii* (De Wild.) Cheesman is native from Sierra Leone to Angola and Malawi, and *Ensete homblei* (De Wild.) Cheesman is native to southern Democratic Republic of Congo and northern Zambia. *Ensete* is not well studied, as the size of all its parts makes it difficult to collect for herbaria. It differs from *Musa* in its large seeds and in its monocarpic habit (i.e. each plant dies after fruiting).

**Growth and development** In natural forest, the seeds of *Ensete ventricosum* are dispersed by birds, monkeys and other animals. Lack of imbibition due to hardseededness is one of the factors delaying germination. The germination of the seed is followed by rapid elongation of the scutellar arm and expansion or swelling of the hypocotyl/epicotyl axis. The micropylar plug is then extruded, the axis emerges through the seed coat and the primary root follows. The primary root is short-lived and is replaced by rapid growth of a ring of seminal adventitious roots. The cotyledon tip remains in the hard endosperm and is joined to the base of the radicle. As a result of elongation of the epicotyl the cotyledon starts to appear out of the hard endosperm. The cotyledonary sheath is a coleoptile-like structure. The second leaf is also sheath-like and the third bears a relatively expanded lamina; finally a growing point with a one-layered white tunica (which later on becomes green) is formed. New leaves emerge successively through the pseudostem. Similar to other musaceous plants, the leaf of *Ensete ventricosum* is fully developed prior to emergence. Soon after emergence it unfurls and the lamina assumes a horizontal position and later bends slightly downwards. About 80 leaves are formed during the life-time of a plant. The shoot of *Ensete ventricosum* consists of a single bud embedded in the swollen axis, a pseudostem and the lamina. At the end of the vegetative phase, the bud starts to grow upwards all the way through the centre of the pseudostem forming the aerial stem on which later the inflorescence develops. The rate of progress from emergence to flowering depends on factors such as landrace/cultivar, altitude, spacing, number of transplantings and soil fertility. In general, enset takes 2–10 years to flower, and about 6 months from flowering to fruiting.

**Ecology** *Ensete ventricosum* occurs naturally in montane forest and riverine forest, often in clearings, gullies and near streams. In Ethiopia it occurs naturally between (500–)1000–1600(–2400) m altitude. In cultivation it occurs at altitudes from 1600–3100 m, but scattered plants can also be found at lower altitudes. However, it grows best at elevations between 1800 m and 2450 m. Climatic conditions at higher elevations, especially low temperature and frost, hamper the growth of the crop and its maturation may take twice as long, or even longer, than in lower regions. For optimum growth enset requires an average annual rainfall of 1100–1500 mm. Although it needs a well-distributed rainfall at the early stages of growth and a fairly high average rainfall, established enset plants can tolerate periods of drought and frost. In Ethiopia, food security is better in enset-based farming systems than in cereal-based ones. Monthly mean temperatures of 16–20°C are optimal, but growth is acceptable from 5–25°C. Enset grows well in most fertile and well-drained soils, ideally moderately acidic to alkaline (pH 5.6–7.3) with 2–3% organic matter.

**Propagation and planting** *Ensete ventricosum* is usually propagated by suckers from an immature corm, but propagation by seeds is occasionally practised in some parts of Ethiopia to increase genetic diversity. Scarification and pre-soaking or temperature treatment of up to 40°C are needed to enhance germination. In vegetative propagation, an immature enset plant is cut 10–15 cm above the junction of the pseudostem and corm. The corm is then split into 2–4 equal parts and the apical bud is removed to break apical dominance and induce the formation of several buds from the mother corm. The split corms are planted immediately or stored in shade for 2–3 days if there is rain. They are planted 1 m apart and 50–150 new suckers appear 4–6 weeks later. In the traditional cropping system, suckers

are separated from the mother corm after 1 year or more, and are planted in a well-manured nursery. Plants are subsequently transplanted yearly into new nurseries until they are finally planted in the field where they are left until harvest. The number of transplantings varies depending on the region and farm, but can be up to four. Where land is less scarce, enset suckers can be planted directly into their final location at a spacing of 2–3 m between rows and 1–1.5 m within rows.

**Management** Important differences in the farming systems exist between the ethnic groups in the comparatively small area of cultivation of enset. The extent to which the staple crop is supplemented by other crops may vary considerably, which has also some bearing on management practices, but all ethnic groups have a prominent interest in cultivating enset. Enset is the main food source among the Gurage, and among the Sidama and related groups. Tuber crops or cereals are other staple crops of the Kaffa in south-western Ethiopia, and of the Wolaita. Tuber crops are more important than enset for the Bench, whereas cereals are more important for the Oromo in West Ethiopia.

Enset is grown as a monoculture of similarly sized plants, or in mixed stands of different sizes, ages and clones. Young enset plants are usually intercropped with annual crops (e.g. maize, beans, cabbage, taro and potatoes), and older plants with perennials (such as avocado, coffee and citrus). Enset is grown closest to the house so that the plants can easily be fertilized with cow dung and house refuse.

Weeding in *Ensete ventricosum* is important especially in the early stages of growth. During the rainy season (May–October), hand weeding and slashing is done 2–3 times depending on the amount of rain and the age of the crop. At later stages, slashing and removal of older leaves once a year is enough. In the dry season, deep cultivation is necessary to remove weeds such as *Cynodon dactylon* (L.) Pers. and *Cyperus rotundus* L.

Enset grows very well around homesteads where animal manure and household refuse are easily spread. These methods of maintaining soil fertility have been common practice in traditional production systems. The amount of manure and frequency of application decrease as the age of the plantation increases. After manuring, transplanted enset suckers are often mulched with dried grasses or plant debris; in the dry season old enset leaves, weeds and animal bedding are also used as a mulch. Enset biomass increases significantly when nitrogen and phosphorus are applied, but the effect on starch yield is limited. Potassium has only a marginal effect on biomass growth but favourably increases starch production. The perennial canopy of enset intercepts heavy rain, thereby reducing soil erosion, and also reduces soil temperature.

**Diseases and pests** The most serious disease of enset is bacterial wilt caused by the bacterium *Xanthomonas campestris* pv *musacearum*. It is present in virtually all enset-growing areas. It is very destructive and kills enset plants at all stages of growth. Current control measures include uprooting and discarding infected plants, planting healthy, disease-free plants from less susceptible landraces, cleaning equipment that has come in contact with diseased plant material, crop rotation, avoiding overflow of water from infested to uninfested fields, removing *Canna indica* L. around enset as it acts as an alternate host and controlling leafhoppers, aphids and mole rats that may transmit the pathogen. Leaf spot diseases caused by the fungi *Phyllosticta* sp., *Piricularia* sp. and *Drechslera* sp. commonly affect suckers, seedlings and young plants. Control measures include thinning overcrowded suckers, regular weeding and avoiding intercropping suckers with tall plants. The fungus *Sclerotium rolfsii* may cause diseases of root, corm and pseudostem. Fungicidal dips would be an appropriate method for controlling fungal root pathogens. Root lesion nematodes (*Pratylenchus goodeyi*) and root knot nematodes (*Meloidogyne* sp.) are commonly found and are widely distributed. *Pratylenchus goodeyi* in particular, is often found associated in large numbers with bacterial-wilt affected plants and is therefore suspected to play a role in the development and severity of the latter disease. Root nematode control includes crop rotation.

Insects such as spider mites, leafhoppers, aphids and mealy bugs are a serious problem in enset cultivation. Porcupines, mole rats and wild pigs will eat enset corms and pseudostems. Farmers use woven fences and ditches as protection around enset fields, and use traps to catch the animals.

**Harvesting** The optimal harvesting time of enset for the preparation of kocho is soon after the appearance of the inflorescence. Enset harvested too young has a low starch content; if harvesting is delayed until flowering, vegetative growth ceases, leaves die, and the inflorescence starts to use up the starch produced. Harvesting

involves removing the whole plant, removing the leaf sheaths from the pseudostem and separating the corm. Plants are harvested earlier for the production of amicho.

**Yield** The yield of *Ensete ventricosum* products is determined by the type of landrace grown, climatic factors, soil fertility, the time to maturity, the methods of processing and the length of the fermentation period. The fresh yield of kocho is 16–42 kg/plant or 12–25 t/ha/year. The fibre yield of enset has been estimated at 500 g per plant.

**Handling after harvest** After harvesting, the leaf sheaths of pseudostems are cut into pieces of 1–1.5 m long, and the soft parenchymatous pulp is scraped off from the leaf sheaths. The remainder may be cleaned and dried for fibre production. The corm and basal part of the stem are grated and mixed with the pulp scraped from the leaf sheaths. This mixture is placed in a pit of about 1 m in diameter and 1 m deep, carefully lined with enset leaves. The pit is sealed by covering it with leaves, which are weighed down with heavy stones. The mixture is then left to ferment for a period of several months. Once every 2–4 weeks the pit is reopened, the content is rearranged and the pit is covered with fresh enset leaves. The fermentation is initiated by the bacteria *Leuconostoc mesenteroides* and to a lesser extent *Streptococcus faecalis*. This lowers the pH from 6.5 to 5.6. During this period a rancid odour is sometimes present due to *Clostridium* spp. After about 2 weeks *Lactobacillus coryneformis* and *Lactobacillus plantarum* continue the fermentation and further lower the pH to 4.2. The product is ready for consumption after 2–4 months but can also be kept for one year or more, provided it is kept under anaerobic conditions. If kocho is exposed to air it spoils quickly due to various moulds causing softness, sliminess and discolouration. For extended periods of storage, it may be necessary to shift the material from one pit to another so that the surrounding enset leaves can be renewed. Fresh enset is not much liked, but in times of shortage of fermented enset a small amount of fermented enset can be mixed with unfermented enset in order to give the desired taste.

Bulla is prepared by kneading fresh unfermented kocho and squeezing out the liquid, which is rich in starch. The liquid is collected and the starch is left to settle. The liquid is then discarded and the bulla is left to dry and fermented in a way similar to kocho.

**Genetic resources** There are many enset landraces. Among the Hadiya ethnic group only, more than 47 enset landraces were identified, including special types with medicinal properties or good fibre yield. Each vernacular name represents a morphologically different enset landrace. Different language groups may have different names for the same landrace making it difficult to identify landraces. Important landraces in Hadiya are: 'Gimbo', 'Sapara' and 'Siskela'; in Sidama: 'Midasho', 'Genticha' and 'Gulumo'; in Wolaita: 'Ankogena', 'Kucha' and 'Alagena'. As there has been genetic erosion due to drought, diseases and expansion of settlement areas, nationwide collection, evaluation, characterization and conservation of enset genetic material has been started by the Ethiopian Institute of Biodiversity Conservation and Research in Addis Ababa and Debub University in Awassa.

**Breeding** Major breeding objectives of *Ensete ventricosum* are tolerance to bacterial wilt, and obtaining landraces or clones that produce an edible corm of good taste, high nutritional value and early maturity. The selection of landraces for lowland enset cultivation is being given major attention.

**Prospects** Because of its tolerance to relatively prolonged soil moisture stress, its multipurpose use and its comparatively high yield, *Ensete ventricosum* has attracted the attention of farmers, researchers and policy makers. As a result, enset is now one of the important crops receiving government funding for research, and its cultivation is being expanded to other parts of Ethiopia. A future interest from other African countries is anticipated. There is also an increasing demand in other parts of the world for the use of enset for ornamental purposes.

**Major references** 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100

**Other references** 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2103

**Sources of illustration** 2101 (inflorescence, fruit, seed), 2102 (habit of flowering plant)

**Authors** Ademasu Tsegaye & E. Westphal

## EUCALYPTUS CAMALDULENSIS Dehnh.

**Protologue** Cat. horti camald., ed. 2: 6, 20 (1832).

**Family** Myrtaceae

**Chromosome number** $2n = 22$

**Synonyms** *Eucalyptus rostrata* Schltdl. (1847).

**Vernacular names** River red gum, Murray

red gum, red gum (En). Eucalyptus rouge, gommier rouge (Fr). Eucalipto vermelho (Po). Mkaratusi (Sw). Red gum is occasionally used for *Eucalyptus camaldulensis*, but refers to several other *Myrtaceae* as well.

**Origin and geographic distribution** The natural distribution of *Eucalyptus camaldulensis* covers most of the Australian mainland, ranging from tropical Northern Territory to cool, temperate Victoria. It is planted in many tropical and subtropical countries, probably being the world's most widely planted tree in arid and semi-arid lands, and has become naturalized in many areas.

**Uses** The wood of river red gum is used mainly for firewood, charcoal, poles, posts and paper pulp. It is also used for hardboard, fibreboard and particle board. Logs may be sawn for construction timber (especially for bridges, wharves and ships), railway sleepers, furniture, flooring and packing cases, although the quality is sometimes poor. River red gum is often planted for shade, as windbreaks, for amenity purposes and as a source of nectar to produce high quality honey. It is planted to rehabilitate saline land, being able to utilize saline groundwater. The bole has potential as a substrate for shiitake mushroom (*Lentinus edodes*) cultivation, and yields a gum (red kino) which can be used as a dye and is used medicinally to treat diarrhoea and pharyngeal inflammations. In Senegal, a leaf decoction sweetened with sugar is used to treat stomach-ache and dysmenorrhoea. An essential oil, obtained from the leaves of mainly tropical provenances, is used for medicinal purposes and is traded as eucalyptus oil.

**Production and international trade** In addition to extensive, but largely unrecorded, small-scale plantings worldwide for fuelwood, shade and shelter, over 500,000 ha of plantations had been established by the mid-1970s, mainly in the Mediterranean region using provenances from southern Australia. This figure has now probably doubled due to better adapted provenances from northern Australia being planted in tropical areas.

*Eucalyptus camaldulensis – planted and naturalized.*

Wood production for domestic consumption is substantial. Wood chips for paper production are exported by several African countries, but statistics for domestic consumption and exports are lacking.

**Properties** The medium-weight to heavy timber is hard and durable. The heartwood has a red colour, turning red-brown upon exposure, and is clearly demarcated from the paler sapwood. The texture is moderately coarse, the grain interlocked, straight or wavy, often producing an attractive figure. The density is 700–980 kg/m$^3$ at 12% moisture content, with samples from natural forest having the higher densities. Density of plantation-grown river red gum wood varies with age, the provenance used and planting site, but does not appear to be closely correlated with rate of growth. Charcoal and pulp yield are positively correlated with density. Provenances from tropical northern Queensland (e.g. 'Petford') produce wood with the highest density and thus the highest yields of charcoal and pulp.

Mechanical properties of samples from Australia at 12% moisture content are: modulus of rupture 101 N/mm$^2$, modulus of elasticity 11,180 N/mm$^2$, compression parallel to grain 55 N/mm$^2$, shear 15 N/mm$^2$, cleavage 89 N/mm radial and 98 N/mm tangential, Janka radial hardness 9745 N, Janka tangential hardness 9525 N and Janka end hardness 10,415 N. The timber is easy to saw despite its high density. Mature material can be seasoned with little degradation. Rates of shrinkage are high: from green to 12% moisture content: 4.4% radial and 8.9% tangential.

The heartwood is resistant to termites; the sapwood is susceptible to attack by *Lyctus* borers. Preservation is necessary if the timber is to be in contact with the ground; the heartwood is extremely resistant, the sapwood is permeable to preservatives.

The wood of plantation-grown river red gum often has unfavourable characteristics such as growth stresses, shrinkage on drying, collapse, spiral grain and starch in the sapwood. Its durability is less than that of trees in natural stands in Australia. Careful post-harvest procedures can ame-

liorate this. The energy value of the wood is 21,000 kJ/kg.

The leaves of river red gum yield traces of up to 3% of an essential oil traded as eucalyptus oil. The chemical composition is variable and is determined mainly by the provenance and to a lesser extent by the environment or the season of harvesting. Differences in the method of extraction also cause differences in composition; hydrodistillation especially causes decomposition of several components. Three main types of eucalyptus oil can be recognized. Many tropical provenances (e.g. 'Petford') yield an oil rich in 1,8-cineole (35–70%) and para-cymene (2–20%) and are a potential source of medicinal-grade eucalyptus oil; oil from subtropical origins is often characterized by cryptone (about 15%) and para-cymene (20–35%) or by spathulenol (15–20%), para-cymene (20–30%) and cryptone (4–7%). Other characteristic components include aromadendrene and alloaromadendrene, α-terpineol and terpinen-4-ol. Several triterpenoid constituents have been isolated from the leaves, e.g. camaldulin, ursolic acid lactone acetate, ursolic acid lactone, betulinic acid, oleanolic acid, amirinic acid and β-sitosterol 3-O-β-D-glucopyranoside. The first 3 compounds have been tested for spasmolytic activity and were found to possess calcium antagonist activity. River red gum is a host tree of *Cryptococcus neoformans*, a biotrophic smut-like fungus causing cryptococcosis, a serious disease in humans usually resulting in meningitis or pneumonia. This infection is locally common in Australia, and has spread elsewhere, where it is often found in AIDS patients.

**Description** Medium-sized to sometimes large tree, commonly up to 20 m tall, occasionally reaching 50 m with a bole diameter of 1(–2) m, in open formations with a short, thick bole and a large, spreading crown, in plantations, with a clear bole of up to 20 m with an erect, lightly-branched crown; bark smooth, white, grey, yellow-green, grey-green or pinkish-grey, shedding in strips or irregular flakes, rough bark may occupy the first 1–2 m of the trunk. Leaves alternate, pendulous, simple; stipules absent; petiole terete or channelled, 12–15 mm long; blade narrowly lanceolate to lanceolate, often falcate, 8–30 cm × 0.7–2 cm, narrowly acute at apex, entire, sclerophyllous, evenly green or grey-green. Inflorescence an axillary, simple, umbelliform, condensed and reduced dichasium, 7–11-flowered; peduncle slender, terete or quadrangular, 6–15 mm long. Flowers bisexual, regular; pedicel slender, 5–12 mm long; flower


*Eucalyptus camaldulensis – 1, tree habit; 2, flowering branch; 3, fruiting branch.*
*Source: PROSEA.*

buds globular-rostrate or ovoid-conical, divided into a hemispherical hypanthium (lower part) 2–3 mm × 3–6 mm, and a rostrate to conical operculum (upper part) 4–6 mm long, which is shed at anthesis and considered to represent the perianth; stamens numerous, on a staminophore; ovary inferior, 3–5-celled, style subulate. Fruit a thin-walled, hemispherical or ovoid capsule enclosed in a woody hypanthium 3–6 mm × 4–10 mm, opening with 3–5 strongly exserted valves, many-seeded. Seeds minute, smooth, yellow-brown. Seedling with epigeal germination and 2-lobed cotyledons; first 4–6 pairs of leaves decussate, subsequent leaves alternate; leaves ovate to broadly lanceolate, 13–26 cm × 4.5–8 cm, green, grey-green or blue-green.

**Other botanical information** There is considerable morphological variation within *Eucalyptus camaldulensis*, which is not surprising given its wide geographic distribution. Six varieties have been described, but this division has been largely ignored because of difficulties in identification. The northern and southern provenances are sometimes accommodated in two varieties: var. *camaldulensis* and var. *obtusa* Blakely,

respectively. Var. *camaldulensis* has rostrate opercula, while var. *obtusa* has obtuse or rounded ones. However, the variation in this character seems to change gradually with location.

*Eucalyptus camaldulensis* is closely related to *Eucalyptus tereticornis* Sm. The latter can be distinguished by its taller and more steeply branched habit, its acutely conical opercula and black, rough-coated seeds. Where both species grow naturally, as in eastern Victoria and Queensland, hybridization and subsequent introgression occurs. Several populations in far northern Queensland, previously identified as *Eucalyptus tereticornis*, show several characteristics of *Eucalyptus camaldulensis* and are now considered a separate subspecies of the latter (subsp. *simulata* Brooker & Kleinig). Among them are the fast-growing provenances 'Laura River', 'Palmer River' and 'Walsh River' that are widely planted in tropical regions. Natural hybrids between *Eucalyptus camaldulensis* and *Eucalyptus alba* Reinw. ex Blume are also reported, while hybridization with *Eucalyptus grandis* W.Hill ex Maiden occurs in plantations.

**Anatomy** Wood-anatomical description:

– Macroscopic characters:

Heartwood reddish, turning red-brown upon exposure, clearly demarcated from the paler sapwood 50–75 mm wide. Grain interlocked, straight or wavy, often producing an attractive figure. Texture moderately coarse. Growth rings often apparent. Gum canals (known as 'kino veins') prominent.

– Microscopic characters:

Growth rings often distinct as a result of some thick-walled latewood cells. Vessels diffuse, 7–10/mm$^2$, predominantly solitary, variable in size, 100–190 µm in tangential diameter; perforation plates simple; intervessel pits alternate, vestured; tyloses abundant. Fibres 760–900 µm long, 12–16 µm in diameter, non-septate, thick-walled, with conspicuously bordered pits mainly on radial walls. Parenchyma moderately abundant, diffuse and vasicentric. Rays 12–16/mm, 1–3-seriate, 14–19 cells high, homogeneous to weakly heterogeneous. Silica bodies absent. Traumatic axial gum canals frequently present.

**Growth and development** Seed germination rate of river red gum is generally high and can reach almost 100%. Lignotubers develop early in the life of northern Australian provenances, but are mostly absent in those from southern Australia. Growth rates vary greatly between provenances and are heavily site-dependent. Although annual seedling growth rates of up to 4(–7) m in height and up to 4(–6) cm in diameter have been recorded for well-adapted provenances on favourable sites in the tropics, in drier areas in Zimbabwe young trees from different provenances were on average slightly over 6 m tall 5 years after planting.

In tropical regions, some provenances may flower almost throughout the year. Pollination is mainly by insects but also by birds and small mammals. Seeds ripen about 6 months later.

River red gum may start flowering when 1.5–2 years old. On favourable sites in the tropics, the period from planting to production of the first seed crop may be as short as 3 years. Eucalypts do not develop resting buds and grow whenever conditions are favourable.

**Ecology** Under natural conditions, river red gum occurs typically along watercourses and on floodplains, very occasionally in southern Australia extending to hills or ranges, usually in open forest and woodland, at 20–700 m altitude. It grows under a wide range of climatic conditions, from temperate to hot and from humid to arid. Annual rainfall in natural stands varies from 250–2500 mm, but planted trees can survive in areas with as little as 150 mm annually. Survival in arid regions depends on the presence of a high water table or seasonal flooding. The length of the dry season may vary from 0–8 months, rainfall distribution varying from a winter maximum in southern regions to a monsoon type with summer rains in northern areas. Mean annual temperatures range from 13–28°C. Mean minimum temperature of the coldest month ranges from 3–22°C, mean maximum temperature of the hottest month from 21–40°C. In general, river red gum tolerates up to 20 frosts per year, but does not tolerate temperatures below –10°C.

River red gum occurs on a variety of soils, commonly on sandy and silty alluvial soils, but occasionally on heavy clays in southern Australia. It is found along the borders of salt lakes and adapted cultivars are grown on saline waterlogged soils in degraded irrigation schemes. These cultivars may be irrigated with saline water. River red gum is not adapted to calcareous soils, except for a few populations in southern and western Australia growing on shallow soils over limestone. Provenances may differ considerably in frost, fire and salt tolerance.

**Propagation and planting** Selection of the proper genetic material for particular planting conditions is of paramount importance. River red gum is usually propagated by seed. One kg of seed and chaff contains 700,000–800,000 viable seeds,

the chaff being ten times heavier than the seed. In general, 1 kg of seed is sufficient to provide plants for 100 ha at a spacing of 3 m × 2 m and the typical seedling recovery rate of 25%. Seed is best stored dry (5–8% moisture content) in air-tight containers at 3–5°C. Viability will be maintained for several years and is still about 30% after being stored for 7 years. No pre-sowing treatment is required. The optimum temperature for germination is 32°C, but a wide range is tolerated. The fine yellow-brown seed and chaff are sown together under shade in a well-drained and sterilized medium and covered very sparingly with sand. After 4 days, seed has germinated and shade should be reduced. When 2 pairs of leaves have developed, seedlings are pricked out into containers such as polythene bags filled with a sterilized potting mix. A polythene bag size of 15 cm × 5 cm proved most economic in Nigeria. Shading is needed for the first week after transplanting, thereafter plants should be fully exposed. Direct sowing in polythene bags or in open nursery beds for the production of bare-rooted planting stock is also practised. Plants can be planted out after 3 months, occasionally after 6 weeks, when they are 30 cm tall. Excessive watering and shade often result in damping-off or in seedlings becoming too tall and weak for easy transplanting.

River red gum is suited to mass vegetative propagation. Cuttings from juvenile shoots (i.e. below the 10$^{th}$ node) root readily in about 30% of genotypes. A major reforestation project in Morocco is based entirely on cuttings of river red gum. Propagation by cuttings is an integral component of breeding programmes. Elite trees are selected in young plantations (5 years old) and felled or girdled to promote coppicing. Coppice shoots of about 1 m long are collected and divided into pencil-sized cuttings with 2 leaf pairs. Half of the leaf blade is then trimmed and the cuttings are dipped into a hormone preparation and planted in pots under mist and shade. Rooted cuttings are usually planted in nurseries to provide further shoots. Methods of *in-vitro* propagation have been developed.

Spacing varies with the management system and depends on the endproducts required. For firewood, spacings as close as 2 m × 2 m are used; for pulpwood, a spacing of 3 m × 2 m is often used. Wider spacings of 4 m × 2 m or 5 m × 2 m are recommended when larger trees are the objective. In plantations, river red gum has a comparatively narrow crown which allows light to reach the forest floor. This is favourable for intercropping with food crops but also allows weed growth. A spacing of 5 m × 2 m is recommended for intercropping during the first 3 years. Application of 100 g of NP or NPK (3:2:1) fertilizer per tree at planting to assist establishment and early growth is common.

**Management** Frequent weeding, up to 3 times per year, is necessary until the canopy closes 3–5 years after planting. Inadequate weed control may lead to complete failure of the plantation. Intercropping may facilitate weed control. Thinning to less than 700 stems/ha at 5 years provides posts, poles, fuelwood and pulpwood, leaving better trees for the production of, for example, sawn timber after 10 years.

Crown dieback, resulting from boron deficiency, is prevalent in parts of Africa, Asia and South America during the dry season and must be corrected. A dosage of 10–20 g of borax per tree is recommended, depending on soil type.

All fast-growing provenances tested coppice well. The rotation may be as short as 3–5 years for small-sized pulpwood, but is generally 8–10 years. In Israel, maintaining a plantation for 5 successive 10-year coppice rotations has been successful, but in general 2–3 coppice rotations of 10–12 years are feasible. Reduction of the number of coppice shoots on a stool is an important, although time-consuming, management operation. In Nepal, a single reduction at 3–6 months to one shoot per stump is recommended. Competition for water can severely reduce yields of interplanted crops.

**Diseases and pests** In the nursery, river red gum is susceptible to various fungi damping-off and fungal leaf diseases. Proper hygiene and watering sparingly minimize damage. Insects (e.g. termites and aphids) and rodents may be troublesome. However, on suitable sites outside Australia, river red gum is relatively free of diseases and pests. Stem canker and leaf diseases proliferate where rainfall and humidity are much higher than in the natural habitat. In the humid tropics, river red gum may be defoliated by fungi including *Cylindrocladium* spp. during the rainy season. The most susceptible provenances suffer mortality and general decline, but well-adapted provenances (e.g. 'Katherine') are little affected. In parts of Africa and Asia, termites attack seedlings and young trees and must be chemically controlled. In Africa, the Eucalyptus snout beetle (*Gonipterus scutellatus*), of Australian origin, feeds on young shoots but is controlled biologically; moribund or newly-felled trees may become infested with an Australian stem borer or the

longicorn beetle (*Phoracantha semipunctata*).

**Harvesting** River red gum is usually grown on a short rotation and clear-felled at an age that maximizes production for a particular end-use. The felling season affects coppice regeneration. Felling during the dry season delays sprouting and increases the risk of the stump drying out. Felling by saw to give a clean-cut short stump with minimum bark damage is best. In coppice systems, e.g. in Nepal, some stems are sometimes left uncut as standards. This practice is recommended to produce wood of a range of diameters suitable for various products.

**Yield** Very high productivity is possible under favourable conditions: a mean annual increment of 70 $m^3$/ha of four-year-old trees planted at 3 m × 2 m on a fertile site with high water availability has been recorded in Israel. However, such conditions are seldom met. In the drier tropics, yields of 5–10 $m^3$/ha per year on a 10–20-year rotation are common, whereas in moister regions up to 30 $m^3$/ha per year may be achieved on 7–20-year rotations. Coppice rotations give higher yields than the initial seedling rotation (e.g. 25–30 $m^3$/ha per year versus 17–20 $m^3$/ha per year in Turkey) and the length of the rotation may be adjusted accordingly.

**Handling after harvest** End-splitting of roundwood may be reduced by felling during winter months. For sawn timber production in Pakistan, it is recommended to fell in October, convert immediately into 70 mm quarter-sawn planks, carefully stack in a well-ventilated room and then top load each stack in order to reduce defects.

**Genetic resources** It is often impossible to trace the origin of *Eucalyptus camaldulensis* seed used for plantations, so the extent of genetic variation available in various areas is uncertain. Systematic introduction of appropriate seedlots from native Australian stands is highly recommended to ensure that a wide genetic variation is used for selection and breeding.

In Australia, two groups of provenances are distinguished: a northern tropical group and a southern temperate group. The better-performing tropical provenances, such as 'Petford' and 'Katherine' are generally the most sought-after for breeding programmes in tropical Africa. The Australian Tree Seed Centre (ATSC) provides well-documented single-tree and bulk provenance collections of river red gum for breeding programmes.

**Breeding** The ideal commercial tree should have good vigour and resistance to diseases and pests, a straight single bole, drought tolerance, good coppicing ability, high pulp yield (light-coloured timber), thin branches and good self-pruning ability, and a thin bark.

Although seed availability of climatically adapted northern Australian provenances has increased, supplies are still insufficient to meet demand. Consequently, a number of tropical countries support selection and breeding programmes, for instance in Zimbabwe. Transgenic lines contain both a gene conferring tolerance of the herbicide glufosinate ammonium and a gene providing insecticidal properties, e.g. against chrysomelid beetle larvae.

**Prospects** River red gum is one of the best performing trees in the seasonally dry tropics for an impressive array of end-products. It is superior to other exotic trees for production of firewood, charcoal and wood for other purposes on infertile dry sites. It tolerates drought and high temperature and grows rapidly when water is available, tolerating periodic waterlogging and soil salinity and (to a certain extent) fire and frost. Its productivity and versatility can be enhanced by breeding programmes now under way in several tropical regions (but few in Africa). With careful selection of provenances, river red gum is expected to gain importance in tropical Africa.

**Major references** 2016, 5765, 5767, 5768, 5769, 5770, 5771, 5772, 5773, 5779

**Other references** 5774, 5775, 5776, 5777, 5778

**Sources of illustration** 5766

**Authors** J.C. Doran & W. Wongkaew

## FAIDHERBIA ALBIDA (Delile) A.Chev.

**Protologue** Rev. Int. Bot. Appl. Agric. Trop. 14: 876 (1934).

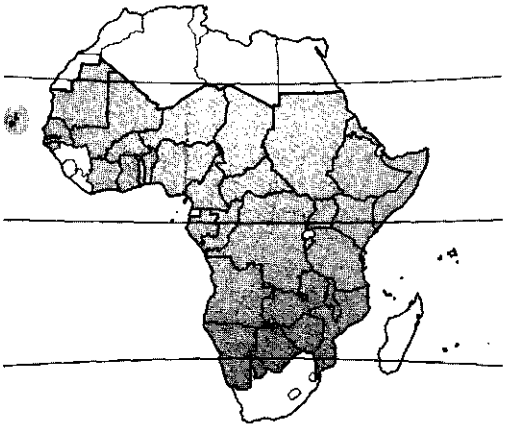
**Family** Mimosaceae (Leguminosae - Mimosoideae)

**Chromosome number** $2n = 26$

**Synonyms** *Acacia albida* Delile (1813).

**Vernacular names** Apple-ring acacia, winter-thorn, white-thorn, ana-tree (En). Arbre blanc, cad, faidherbier (Fr). Espinheiro de Angola (Po). Mgunga, mkababu (Sw).

**Origin and geographic distribution** The origin of *Faidherbia albida* is unclear. It has been postulated that it originated in the Sahara before desertification, but also that it was originally a riverine tree of eastern and southern Africa that was introduced through pastoralism and agricul-



*Faidherbia albida – wild and planted.*

ture into western Africa, where it is only found on cultivated or previously cultivated land. It has long been preserved and protected on croplands by African farmers. However, this practice has become much less common in recent years. *Faidherbia albida* occurs all across the African continent, encircling the central African forest massif, from the Atlantic coast (Senegal, Gambia) to the Red Sea (Egypt, Sudan, Eritrea and Somalia) and from there to South Africa, Lesotho, Namibia and Angola. Its northern limit is not well defined because it occurs along watercourses and in areas where groundwater is present (e.g. in south-western Morocco, mountain massifs in the Sahara, and along the Nile in Egypt). Elsewhere, *Faidherbia albida* occurs in Yemen, Saudi Arabia, Israel, Jordan, Lebanon, Syria and Iran, and has been introduced into Ascension Island, the Cape Verde Islands, Cyprus, India, Pakistan and Peru.

**Uses** *Faidherbia albida* is an ideal multipurpose agroforestry tree that is widely retained or planted in dry, densely populated areas of West and East Africa where fallow periods have become very short or have disappeared. Its 'inverted phenology' (leafless during the rainy season and in leaf during the dry season), and ability to fix nitrogen and draw water and nutrients from deep soil layers, has a beneficial effect on the microclimate, soil fertility and soil moisture for associated crops. It is therefore commonly intercropped with annual crops, especially pearl millet and groundnuts. Leaves and pods are an excellent fodder in the dry season. Branches are pruned more or less intensely by herdsmen for use as fodder. Pods are sometimes also used as fodder for domestic animals.

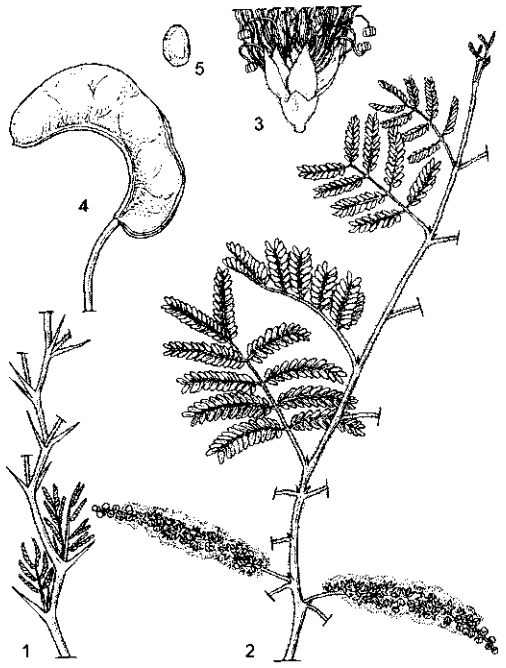
The wood is commonly used for handicraft and implements, and for the construction of houses, barns and grain stores. It is not long lasting and is sometimes soaked in water for several months to remove the sap and make it more resistant to insect attack. It is an excellent firewood and can be converted into high quality charcoal. The spiny branches are used for fencing fields.

Bark and roots, alone or mixed with other components, are common ingredients of traditional medicinal preparations for external or internal usage. These preparations are prescribed for respiratory infections, sterility, digestive problems, dysentery, backache, malaria, fever, heart and circulatory problems, dental infections and deafness. The bark is also used for making beehives, for stuffing saddles and in hut construction. Soap is made from the wood ash, which also has depilatory action. Pods can be used as fish bait. Seeds are eaten during famine but require long and elaborate preparation. *Faidherbia albida* has religious significance amongst some tribes, e.g. as a graveyard tree.

**Properties** The nutritional value of leaves, flowers and pods is excellent and they constitute a fodder supplement rich in phosphorus, digestible proteins and carotene. The net energy value is 6–7 MJ/kg dry matter for leaves and pods with 12–15% of digestible proteins in leaves on a dry weight basis, and 6–11% in pods. The mineral content of the pods and leaves is satisfactory except for a deficiency of sodium and the trace elements copper and zinc. The pods also lack manganese. The bark is rich in tannins, ca. 28%, but pods contain only 5%. An oil can be extracted from the seeds, with a yield of 3–10%. *Faidherbia albida* extracts did not show antibiotic activity in pharmacological tests.

The wood is a medium-weight hardwood. At 12% moisture content, the density is 580–710 kg/m$^3$, modulus of elasticity 8600–9400 N/mm$^2$, compression parallel to grain 41–54 N/mm$^2$, shear 6.4 N/mm$^2$, cleavage 16–21 N/mm tangential and Janka side hardness 3500–5200 N. The rates of shrinkage from green to oven dry are 3.7–4.6% radial and 8.4–8.6% tangential, which can be rated as average. The wood glues well and has excellent nailing properties. It is possible to produce bleached chemical pulp from the wood for the paper industry, but the quality is poor and the yields low. The energy value of the wood is about 19,750 kJ/kg, which is considered excellent for use as firewood.

**Description** Medium-sized to fairly large tree up to 20(–30) m tall, with bole up to 100(–150) cm in diameter; bark smooth when young but becom-




*Faidherbia albida – 1, part of young shoot; 2, flowering branch; 3, flower; 4, fruit; 5, seed. Redrawn and adapted by W. Wessel-Brand.*

ing fissured and flaky with age, brown to whitish-grey; branches with paired stipular, straight spines up to 3 cm long. Leaves alternate, bipinnately compound; petiole 0.5–3.5 cm long, eglandular; rachis 3–7.5 cm long, with 2–12 pairs of pinnae with a gland at the junction of each pinna pair; pinna rachis 2.5–5.5 cm long, with 6–23 pairs of leaflets; leaflets oblong, 2.5–12 mm × 0.7–5 mm, glabrous to pubescent. Inflorescence a dense axillary spike 3.5–16 cm long, with a peduncle 2–4 cm long. Flowers bisexual, 5-merous, successively white, cream and then yellow, sessile or with a pedicel up to 2 mm long; calyx up to 2 mm long; petals up to 3.5 mm long; stamens numerous (usually 40–50), 4–6 mm long, connate for about 1 mm at base; ovary superior, 1-celled, pubescent, style filiform. Fruit an indehiscent, falcate or coiled pod 6–25(–35) cm × 2–3.5(–6) cm, bright orange to reddish-brown, septate, 10–30-seeded. Seeds ellipsoid-lenticular, 9–11 mm × 6–8 mm, dark brown and shiny, with large central areole.

**Other botanical information** *Faidherbia albida* is often included in the genus *Acacia*. It is distinct in having an eglandular petiole, basally connate filaments, eglandular anthers, and peculiar pods. The separation into the monotypic genus *Faidherbia* is also supported by its pollen structure and by its phenology: leafless in the wet season and leafy in the dry season. The existence of two forms ('races') of *Faidherbia albida* has been recorded for East Africa, differing mainly in the degree of pubescence. However, numerous intermediate forms can be found in several regions. Populations in Ethiopia show more similarity with those in West Africa than with those in nearby East Africa.

**Anatomy** Wood-anatomical description:
– Macroscopic characters:
Heartwood yellowish-white, sometimes dark brown in the heart of old trees, not clearly demarcated from the sapwood. Grain interlocked. Texture coarse.
– Microscopic characters:
Growth rings absent or indistinct. Vessels diffuse, 2–5/mm$^2$, solitary or in radial multiples of 2–3, mean tangential diameter 100–200 µm; perforation plates simple; intervessel pits 7–10 µm. Fibres 800–1500 µm long, moderately thick-walled. Parenchyma in wide, slightly sinuous bands. Rays 14–18/mm, 1–2-seriate, storied, entirely composed of procumbent parenchyma cells. Crystals in the septate parenchyma bordering the fibres.

**Growth and development** The seedling first develops a taproot which can grow down very deeply until it reaches an adequate supply of water. Only then does the young stem start to grow. After 90 days, the taproot may attain a depth of 90 cm and the stem a height of 30 cm. Humid zone provenances develop more extensive lateral rooting near the soil surface, whereas trees in dry zones develop a more prominent taproot. In good conditions, annual growth in height of young trees may be 1–1.5 m. The width of growth rings varies from 1 mm to more than 20 mm.
The tree sheds its leaves at the beginning of the rainy season and comes into leaf again in the dry season. The physiology controlling this process is not yet understood. Flowering starts around the seventh year. The inflorescences appear about 2 months after the leaves. The fruits mature about 3 months after flowering. They are relished by livestock and game, including elephants, which may disperse the seeds. The seed coat is tough, waterproof and leathery, and maintains seed viability for many years. The total lifespan of the tree is generally 70–90 years.
*Faidherbia albida* forms root nodules and fixes

nitrogen with slow-growing *Bradyrhizobium* spp. Nodulating bacteria and nodules have been found at great depth. Under experimental conditions root nodules have also been found with *Rhizobium* spp. Mineral nutrition is enhanced by symbiosis with endomycorrhizal fungi such as *Glomus* spp. and *Gigaspora* spp. Symbiotic mycelia have been found up to 30 m deep in the soil, enabling recycling of nutrients from such depths. A relationship between infection by root-knot nematodes, *Bradyrhizobium* and endomycorrhizal fungi resulting in stimulation of the formation of N-fixing nodules has been found, but this observation needs further investigation.

**Ecology** *Faidherbia albida* occurs in a wide range of habitats from deciduous forest (as in the Guinea zone), riparian forest, savanna woodland to sand dunes and depressions in the desert where its roots can reach ground water. It grows in a wide range of climatic conditions, but it needs a long and distinct dry season and access to permanent ground water. Under natural conditions, it is found particularly in association with water, e.g. along rivers and in gullies and ravines. Its prefers an annual rainfall of 500–800(–1000) mm, but in Mediterranean climates with winter rains 100–400 mm are sufficient. In more humid habitats it cannot compete with other vegetation. It occurs from sea level to 2000(–2500) m altitude. *Faidherbia albida* prefers deep, light sandy to moderately heavy soils, but also occurs on heavier soils, even clay soils. It tolerates waterlogging or flooding for several months, as occurs along the Nile and in rice fields in Senegal.

**Propagation and planting** Under natural conditions, reproduction is by seed and root suckers. In some regions (e.g. western and southern Africa) propagation by seed is the rule, whereas in other regions (e.g. in the Middle East) suckers prevail. In Sudan, trees reproduce equally well by seed or suckers.

Seeds can best be collected from nearly ripe fruits while still on the tree, as the fruits are eaten by game and livestock almost as fast as they fall to the ground. Moreover, completely ripe seeds are often infested with insects such as Bruchid beetles. Fruits are mechanically hulled. *Faidherbia albida* has orthodox seeds. Green seeds do not store well and must be sown at once, but ripe seeds can be stored after drying and treatment against insects either at ambient temperature (for at least 3 years) or at 1–4°C (many years). Green seeds do not need treatment before sowing, but ripe or stored seeds should be treated with sulphuric acid, immersed in boiling water or scarified, after which germination rates of 75–100% after 30 days have been obtained. In the nursery, seeds are planted in polythene bags (30 cm high and 8 cm in diameter). Watering 2 times a day is recommended. After 3–4 months, seedlings are 15–30 cm tall and can be planted in the field. Spacing is usually 10 m × 10 m.

Tests in Burkina Faso have shown that vegetative propagation of *Faidherbia albida* by cuttings is feasible, with a success rate of about 50% for coppice shoots and root cuttings. In Mali, however, trials with cuttings showed little success. Micropropagation is still at an experimental stage.

**Management** *Faidherbia albida* often occurs in a park-like vegetation named 'Faidherbia parks', especially in West Africa, where it is widely intercropped with annual crops. Studies on the microclimate under *Faidherbia albida* trees demonstrated the beneficial effects of this on cropping. In densities of 20–30 trees/ha, the potential evapotranspiration decreases by 50% during the dry season and 10% during the wet season compared with cropping without trees. The soil dries out more slowly. *Faidherbia albida* slightly improves the internal cohesion and porosity of the soil, while soil organic and biological characteristics are strongly improved. In Senegal, increases in total carbon (62%), mineralizable carbon (73%), humus (40–47%) and total nitrogen (50%) have been demonstrated under a *Faidherbia albida* canopy. Soil conductivity, pH, and cation reserves were higher but the difference was not significant. However, the exchange capacity, the assimilated phosphorus, and the biological activity of the soil were significantly increased. The litter is of good quality.

It has been demonstrated that 45% of total nitrogen in the stem of young plants is the result of nitrogen fixation.

Yields of millet are much higher under a *Faidherbia albida* canopy; increases of 50–150% have been recorded. Results for sorghum, cotton, groundnut and maize are variable and either positive or negative, depending on the study. The effect may depend on soil fertility; when this is high, *Faidherbia albida* competes with the crops. The main causes of mortality during the first year are accidental cutting during weeding of the associated crops, and the failure to control browsing by goats and sheep after crop harvesting. Protection against browsing is essential for at least the first 2 years after planting, while the use of marker stakes may reduce damage during weeding. Two weedings a year are essential for a

period of 3 years to prevent young trees from being overtopped by weeds. Later, pruning is necessary so that crop cultivation beneath the trees is easier.

**Diseases and pests** In Niger and Burkina Faso, the nematodes *Meloidogyne javanica* and *Meloidogyne incognita* attack young plants in the nursery; older plants are resistant. Cochineal insects may also cause damage in the nursery; treatment with parathion is effective. Defoliating caterpillars (notably *Crypsotidia conifera*) are the main pest of adult trees, defoliating trees in Nigeria and Zimbabwe by up to 50%. Infestation of seeds is mainly due to larvae of Bruchid beetles. Parasitic plants, such as *Agelanthus dodoneifolius* (DC.) Polhill & Wiens, and strangler figs, such as *Ficus thonningii* Blume, may infect the trees, but cause little damage.

**Yield** Average annual production of organic matter, measured under some large trees in Senegal, was about 100 kg/tree of leaves, 45 kg/tree of bark and small wood, and 125 kg/tree of fruits. Regular lopping reduces fruit production. The yield of fuelwood in adult trees is about 0.1 $m^3$/year.

**Genetic resources** *Faidherbia albida* was a priority species within the FAO project 'Genetic resources of trees for the improvement of life in arid and semiarid zones' (1979–1985) concerning exploration, evaluation and conservation of genetic resources of dry zone species in 16 countries in the Sahel and northern Sudan zones. Seed collection and provenance trials have been carried out in many of these countries. The most comprehensive collection of germplasm is at Centre National de Semences Forestières, Ouagadougou, Burkina Faso, with 48 accessions.

**Prospects** In many parts of Africa, farmers have used *Faidherbia albida* in agroforestry systems for a very long time, highly appreciating this truly multipurpose tree. However, in many areas traditional knowledge of the benefits of this species has faded, and its use is neglected. A new impetus is needed to maintain or restore the use of *Faidherbia albida* in farming systems in the drier zones of tropical Africa, where it can help soil productivity and enable more intensive land use, especially where increasing population density is dangerously shortening fallow periods. More research is needed on genetic improvement to provide farmers with good planting material. Trials are needed to determine preferred spacings in agroforestry.

**Major references** 5453, 5454, 5455, 5456, 5457, 5458, 5459, 5460, 5461, 5464

**Other references** 2048, 5449, 5450, 5451, 5452, 5462, 5463, 5465, 5466, 5467, 5468, 5469, 5470, 5471, 5472, 5473, 5474, 5475, 5476, 5477

**Sources of illustration** 4759

**Authors** C. Bernard

## GNETUM AFRICANUM Welw.

**Protologue** Trans. Linn. Soc. 27: 73 (1869).

**Family** Gnetaceae

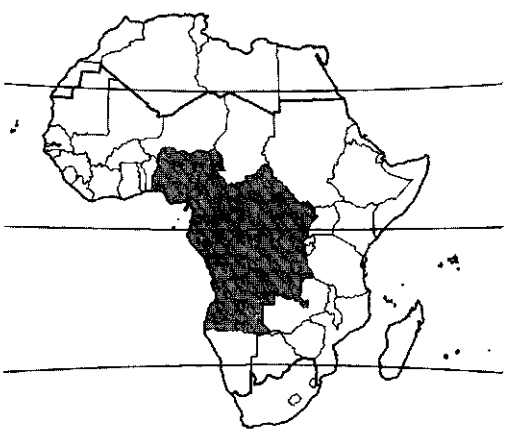
**Chromosome number** $2n$ = unknown

**Vernacular names** Eru (En). Koko (Fr).

**Origin and geographic distribution** *Gnetum africanum* occurs naturally in the humid forest zones from Nigeria to the Central African Republic and to Angola. Eru is hardly cultivated at all at present, but there is massive exploitation of the remaining natural stands, which have almost disappeared in Nigeria and are becoming scarce in other countries.

**Uses** Fresh leaves of *Gnetum africanum* and the very similar *Gnetum buchholzianum* Engl. are widely used as a vegetable although they are rather leathery. They are usually cooked with meat or fish and occasionally consumed as a salad. Leaves are shredded into thin strips and are often eaten as part of a mixture in, for example, a groundnut-based stew. The leaves frequently replace meat because of their high protein content. To soften this rather tough vegetable, people usually mix it with waterleaf (*Talinum triangulare* (Jacq.) Willd.). Shredded leaves can be dried and preserved for later use. The seeds are eaten in Cameroon and the Democratic Republic of Congo.

In Nigeria, *Gnetum* leaves are used for treatment



*Gnetum africanum* – *wild.*

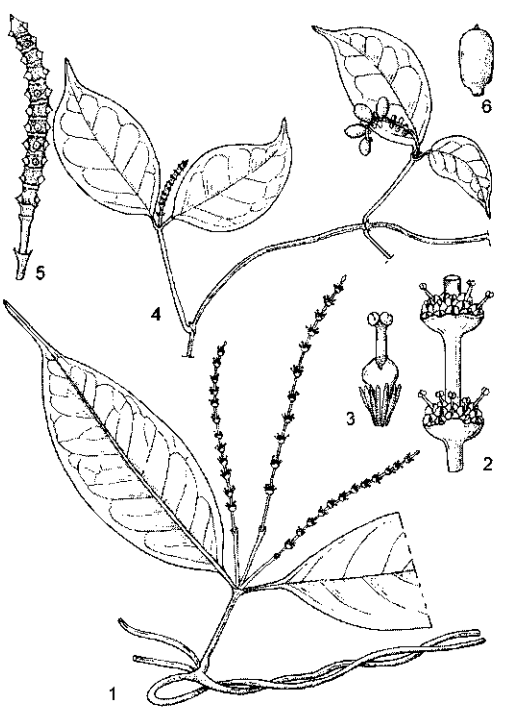
of piles and high blood pressure and also as medicine against enlarged spleen, sore throat and as a purgative. In the Central African Republic the leaves are eaten to treat nausea and as an antidote to arrow poison made from *Periploca nigrescens* Afzel. In Cameroon the leaves are chewed to mitigate the effects of drunkenness and they are taken as an enema against constipation and to ease childbirth. They are also used to treat boils and fungal infections on the fingers. The supple stem is sometimes used as rope.

**Production and international trade** In trade, a distinction is rarely made between *Gnetum africanum* and *Gnetum buchholzianum*. The recent growth in popularity has caused massive destructive exploitation of the remaining natural stands. Most eru is consumed locally, but intensive trade has developed from Cameroon and more recently also from Gabon and the Central African Republic to meet the large demand in Nigeria. Most eru from Cameroon, Gabon and the Central African Republic is transported to Idenau, a coastal village in Cameroon, and from there illicitly by boat to Nigeria. Estimates for the annual export of eru leaves to Nigeria range between 2500 t and 4000 t. Another major marketing centre is the Koilo Region in Congo for which, however, no quantitative data are available. Other marketing centres in Cameroon are Campo near Kribi for the export to Gabon and the Mfoundi market in Yaoundé. In 2000, forest dwellers living near Yaoundé in Cameroon received about 100 FCFA per kg eru vines; after transport to Idenau the value of these vines rose to 400 FCFA per kg. Dried shredded leaves are exported, mainly from Nigeria to the United States and to a lesser extent from other countries to either France or the United Kingdom. Shredded leaves were sold in Nigeria for the equivalent of 4000 FCFA per kg, while 1 kg dried, shredded leaves sells in the United States for US$ 13–45.

**Properties** The leaves of *Gnetum africanum* from Congo contain per 100 g dry weight: carbohydrates 70 g of which 40 g is cellulose, protein 16.5 g, lipids 6 g and ash 7 g. The high protein and fat content of eru leaves explain why they are often used as a substitute for meat. All 8 essential amino acids are present in eru. The essential amino acid content per 100 g dry weight is: isoleucine 0.7 g, leucine 1.4 g, lysine 0.8 g, methionine 0.2 g, phenylanaline 1.0 g, threonine 0.8 g, tryptophan 0.2 g and valine 0.9 g. Analyses of samples of *Gnetum africanum* from several countries are similar. The nutritional value of *Gnetum buchholzianum* is consistently higher than that of *Gnetum africanum*, reflecting the preference of consumers for the former. Eru leaves of both *Gnetum africanum* and *Gnetum buchholzianum* contain C-glycosylflavones, including 2"-xylosylisoswertisin and 2"-glucosylisoswertisin, two compounds that are only known from these two species; characteristic of *Gnetum africanum* are the presence of 2"-O-rhamnoylisoswertisin and apigenin-7-hesperidoside and the absence of vitexin and 2"-O-glycosylvitexin.

**Adulterations and substitutes** If *Gnetum* is not available, it can be substituted with the leaves of the shrub *Lasianthera africana* P. Beauv., which impart a similar taste to the dish.

**Description** Dioecious liana up to 10 m long but sometimes longer; branches somewhat thickened at the nodes, glabrous. Leaves decussately opposite, sometimes in whorls of 3, simple; stipules absent; petiole up to 1 cm long, canaliculate above; blade ovate-oblong to elliptical-oblong, rarely lanceolate, 5–14 cm × 2–5 cm, base attenuate, apex abruptly acuminate, obtuse or minutely apiculate, entire, thick-papery, glabrous, pale green above, paler beneath, with 3–6




*Gnetum africanum – 1, branch with male inflorescences; 2, part of male inflorescence; 3, male flower; 4, branch with female inflorescence and infructescence; 5, female inflorescence; 6, seed. Redrawn and adapted by W. Wessel-Brand.*

pairs of strongly curved lateral veins looped near the margin. Inflorescence an unbranched catkin, axillary or terminal on a short branch, solitary but male inflorescences at apex of branches often in groups of 3, up to 8 cm long, jointed, peduncle 1–1.5 cm long, with a pair of scale-like, triangular bracts; male inflorescence with slender internodes and whorls of flowers at nodes; female inflorescence with slightly turbinate internodes and 2–3 flowers at each node. Flowers small, ca. 2 mm long, with moniliform hairs at base and an envelope; male flowers with a tubular envelope and exserted staminal column bearing 2 anthers; female flowers with cupular envelope and naked, sessile ovule. Seed resembling a drupe, ellipsoid, 10–15 mm × 4–8 mm, apiculate, enclosed in the fleshy envelope, orange-red when ripe, with copious endosperm.

**Other botanical information** *Gnetum* comprises approximately 35 species of small trees, shrubs or most often lianas, found in tropical South and Central America (about 7 species), Africa (2 species) and Asia (about 25 species). They look much like dicotyledonous flowering plants (having opposite leaves with a net venation and cherry-like seeds), although in fact they are gymnosperms. The 2 African species, which are very similar, have been classified in section *Gnetum*, subsection *Micrognemones*. *Gnetum africanum* has leaves which are relatively thin and pale green. Its male catkins often appear to occur in groups of 3 and are of equal width from the base to the tip with flower whorls evenly spaced. *Gnetum buchholzianum* has dark green leaves which are thicker. The male catkins have internodes that are wider at the base than towards the terminal part.

**Growth and development** The two African species of *Gnetum* are lianas with two different types of stems. The orthotropic ones have small, scale-like leaves and rapidly grow vertically, reaching the main branches of a tree where they produce plagiotropic stems with fully developed leaves. The orthotropic stem continues climbing until it reaches the canopy where it branches into several leafy stems. Female plants often show more vigorous growth with stronger stems than male plants. This is more obvious in *Gnetum africanum* than in *Gnetum buchholzianum*.

Eru continues to grow during the dry season and new shoots may develop where the stem has been cut or where side shoots have been removed. New shoots are also formed from rhizomes that spread along the forest floor.

The distinctly coloured drupe-like seeds are probably dispersed by animals such as birds.

**Ecology** Eru can be found in rain forest from sea level up to about 1200 m altitude, and prefers an annual rainfall of about 3000 mm. It is usually found with other climbers on middle and understorey trees, frequently forming thickets. It can also be found in riverine forest in areas that would otherwise be too dry for the species. *Gnetum africanum* is mostly found at the periphery of primary forest and in secondary forest. Today, it is more common than *Gnetum buchholzianum*, which is mainly found in primary forest, especially near openings created by fallen trees.

**Propagation and planting** Eru is hardly cultivated because its seed is very slow to germinate, taking one year or more to do so. It is assumed that seeds first need pre-treatment, such as passing through the intestines of a bird, fruit bat, squirrel or other animal, before they germinate. Seed is normally found only in the tree canopy. Seed collection is thus far from easy, a further reason why eru is hardly cultivated. Methods of vegetative propagation using leafy stem cuttings have recently been developed. It is recommended that leaf blades of such cuttings be trimmed in half. Nursery beds under shade and made of well-decomposed sawdust or fine river sand can be used for propagation.

Ectomycorrhizae assist the roots in absorption of nutrients; the most common species reported is *Scleroderma sinnamarense*. After about 6 weeks the rooted cuttings are transferred to polythene sleeves, bamboo pots or other containers where they remain for a further 2–3 months. The soil mixture for these containers consists of 25% sand and some compost, supplemented with forest soil. Field planting, preferably next to a young tree or shrub, takes place at the beginning of the rainy season.

**Management** Eru is still mainly collected from wild stands, but farmers often retain it when clearing fields. If cultivated, farmers need to provide support, e.g. by using commercial plantations of rubber trees, oil palm and other tree crops. Fences were only found to be successful when there is enough shade, and they are generally too expensive. Fully exposed plants do not grow well; their leaves are thin and pale green, and traders reject them. In experiments, nutrients, especially nitrogen, have shown a positive effect on growth and rate of leaf development.

**Diseases and pests** Mealy bugs are the main pest in the nursery. When eru is grown along dead poles attacked by termites, these insects will damage adjacent leaves. Diseases have not been

found to reduce productivity of eru.

**Harvesting** The current method of harvesting, especially for export trade, is to either uproot whole plants or pull the stems from trees. This leads to large-scale destruction of natural stands. Occasionally, trees have to be cut to reach leafy stems in the canopy. This is mainly done during the dry season when the forest is more accessible and when there is little work on the farm. Controlled harvesting, in which only side shoots or parts of stems are collected, is clearly better than destructive harvesting. After controlled harvesting, new shoots may develop where a stem has been cut or where side shoots have been removed. Preliminary observations indicate that 3–4 harvests per year are possible, still allowing substantial regrowth. More frequent harvesting will result in thin leaves that are considered inferior. The first harvest may take place 6–9 months after planting. The total lifespan of eru is estimated at over 10 years.

**Yield** Preliminary observation indicates that during the first year the fresh leaf yield of eru will be about 2 kg/m$^2$. This may double in subsequent years.

**Handling after harvest** Leafy stems of eru remain fresh for at least a week. Stems collected from the forest are brought to collecting points from where they are either sold in the local market or exported. For this trade, whole leafy stems are packed in large bales. Selection takes place on size and texture of the leaves, and mainly determined by species. *Gnetum buchholzianum* is more popular with consumers and also more expensive because its leaves are generally thicker than those of *Gnetum africanum*. Leaves are shredded before consumption or prior to drying.

**Genetic resources** Demand from Nigeria for home consumption and export has caused large-scale destructive harvesting of *Gnetum* in neighbouring Cameroon and collection for export now also takes place in Gabon and the Central African Republic. There is an urgent need to collect and preserve the diversity found within the two African *Gnetum* species, preferably throughout their natural range. Accessions need to be evaluated for their agronomic potential and for their ability to germinate without the need for interventions. A small collection is currently held at the Limbe Botanic Garden, Limbe, Cameroon.

**Prospects** Alternatives to destructive harvesting of eru should be found. Once the new methods of propagation and cultivation have been adopted there is scope for development of eru as a new crop, for which there is already a high demand and for which an attractive price could be paid. Diversity found between accessions is considerable, offering scope for improvement of both quality and productivity. Research work is currently undertaken at Limbe Botanic Garden, Limbe, Cameroon.

**Major references** 2003, 2115, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2131

**Other references** 2020, 2106, 2111, 2112, 2113, 2114, 2116, 2117, 2118, 2119, 2120, 2121, 2130

**Sources of illustration** 2129 (branch with male inflorescences, part of male inflorescence, male flower), 2130 (branch with female inflorescence and infructescence, female inflorescence, seed)

**Authors** R.R. Schippers & M.T. Besong

## HAGENIA ABYSSINICA (Bruce) J.F.Gmel.

**Protologue** Syst. nat. 2(1): 613 (1791).

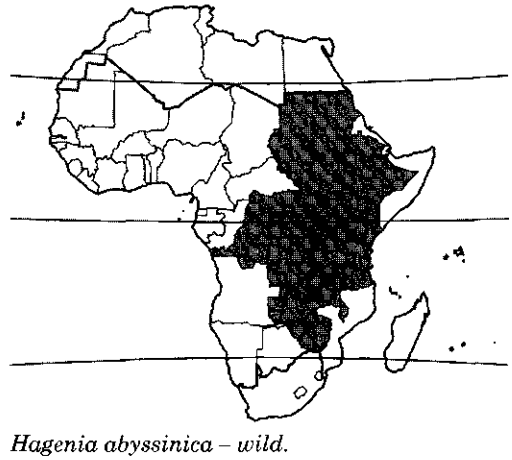
**Family** Rosaceae

**Chromosome number** $2n$ = unknown

**Synonyms** *Brayera anthelmintica* Kunth (1824), *Hagenia anthelmintica* (Kunth) Eggeling (1940).

**Vernacular names** Kosso, kousso, cusso (En). Kosso, kousso, cousso, cossoutier (Fr). Mturunga, mdobore (Sw). In Amharic (Ethiopia) the name 'kosso' can be used to indicate the tree, inflorescence, medicine, or parasite (tapeworm) treated with the plant.

**Origin and geographic distribution** *Hagenia abyssinica* is indigenous to montane regions of eastern, central and southern Africa, mostly



*Hagenia abyssinica – wild.*

above 2000 m altitude. It is found in the Democratic Republic of Congo, Sudan and Ethiopia, and south to Malawi, Zambia and Zimbabwe.

**Uses** Throughout history, *Hagenia abyssinica* has been used as an anthelmintic in Ethiopia and other parts of Africa. Almost every Ethiopian used to drink an extraction of dried flowers once every 1–3 months to expel tapeworm, which was, and to some extent still is, a common parasite in Ethiopia where raw meat, a source of infection, is a delicacy and a very popular item in the diet. Honey, obtained from beehives located near *Hagenia abyssinica* trees and collected immediately after their flowering, is also said to be effective in expelling tapeworms. In the 19th Century, kosso was widely used as an anthelmintic in Europe. It is also used, often in a mixture with parts of other plants, as a medicine to treat syphilis, scrofula, malaria, fever and cough. *Hagenia abyssinica* has strands of red flowers, giving the tree ornamental value. The wood has a handsome appearance and is suitable for furniture, cabinet work, floors, veneers, tools and fences. In Tanzania, *Hagenia abyssinica* is grown in agroforestry systems; the wood is used as fuel, the leaves as fodder and green manure, and the seeds as a condiment or spice. In the Kilimanjaro area, the bark is used for dyeing textiles yellowish red.

**Production and international trade** *Hagenia abyssinica* has been used in Ethiopia for centuries. It became known to European medicine as a tapeworm remedy early in the 19th Century. Before 1950, kosso was listed as an anthelmintic in the pharmacopoeias of about 30 countries. With the advent of chemical anthelmintics with reliable dosage and action, the international use of kosso as tapeworm expellent disappeared. At present, kosso is still locally traded and used in Ethiopia where it is on sale in almost every traditional market. However, its use is rapidly diminishing. The average weight of samples of dried flowers sold in Ethiopia is about 24 g (considered enough for one treatment), samples usually varying between 10–50 g.

**Properties** Kosso is an anthelmintic and also acts as a muscle poison in some small animals. The active principles in *Hagenia abyssinica* flowers are phloroglucinol derivatives, called kosins: kosotoxin, protokosin, kosidin, α-kosin and β-kosin. All are mixtures of isobutyryl, isovaleryl and 2-methylbutyryl side chain homologues of methylene-bis-pseudo-aspidinol. The kosins are presumably located in the glandular hairs.

Several plant species were used in Ethiopia to combat tapeworm infection, but kosso became the most popular and it became customary for people to have 'a kosso day' every 1–3 months. The extract is drunk before breakfast; about 0.5–3 hours later its laxative action starts. The head of the tapeworm (scolex) is seldom expelled, so the worm can regrow, hence the need to repeat the treatment every 1–3 months.

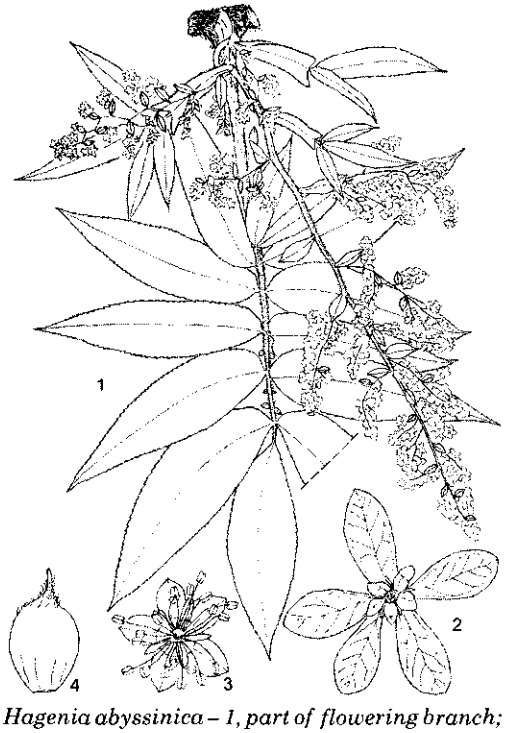
The efficacy of kosso as anthelmintic depends on dosage and the health of the patient. Strong doses of kosso can cause fainting, visual disorders or even death. Usually a dose of 8–16 g of dried flowers is taken, but some people use as much as 35 g. Although it is often stated that female flowers should be used, most tests reveal no difference in effect between male and female flowers. They can be as effective as the chemical anthelmintics dichlorophen, niclosamide and praziquantel. Side effects may include irritation of the gastrointestinal tract, salivation, nausea, headache, fainting spells, general weakness and diarrhoea. Some believe that side-effects are more severe when male flowers are used, and that male flowers have greater emetic activity. Health organizations currently discourage the use of kosso because the dosage of the active principle cannot be controlled by using the flower extract. In mice, doses up to 16 times the lethal dose by the intraperitoneal route produced no observable toxicity by the oral route; high doses affected peripheral vision in chicken. *In-vitro* tests have shown cytotoxic effects against carcinomous cells. Niclosamide (trade name 'Yomesan') is probably the best chemical medicine against tapeworm. It is effective against most types of tapeworm in the gut, but not against cysts outside the gut.

The sapwood is creamy-yellow; the heartwood dark red to red-brown, soft and moderately heavy (560–750 kg/m$^3$ at 12% moisture content). The wood is usually straight-grained with occasionally some silver grain when cut radially. Kosso wood is not durable, and is subject to attack by borers and termites. Distortion during air drying may be severe. Average shrinkage from green to 12% moisture content is 1.6% radially and 4.0% tangentially, and from green to oven dry 2.8% radially and 6.3% tangentially. The wood is fairly easy to saw. Planing may be difficult due to interlocked grain, but the moulding, boring and turning properties are satisfactory. Pre-boring before screwing is essential. Nail-holding power is high. The heartwood is very resistant to impregnation.

**Adulterations and substitutes** Finely pow-

dered kosso can easily be adulterated by any other brownish powder, whereas intact flower parts are very distinctive and cannot be adulterated. In Ethiopia, there are many plants with anthelmintic activity; fruits of *Embelia schimperi* Vatke ('enkoko') are most often used here as a substitute for kosso.

**Description** Dioecious, small to medium-sized tree, up to 20 m tall; bole rarely straight, up to 60(–220) cm in diameter; bark pale red-brown, flaky; crown wide, umbrella-shaped; young branches densely covered with short, villous hairs and long, erect, silvery, soft, often glandular hairs turning reddish-green, with ring-like, long persisting leaf scars. Leaves alternate, imparipinnate, up to 50 cm long; petiole up to 15 cm long, with 2, up to 1.5 cm wide, thin, leafy lateral wings (adnate stipules) at base surrounding the twig as a sheath; leaflets up to 17, alternate to subopposite, subsessile, narrowly oblong to elliptical, 9–15 cm × 2–5 cm, obliquely obtuse at base, acuminate at apex, margin serrate and long silky hairy, the teeth usually ending in a thickened gland, pinnately veined with veins prominent below and having long silky hairs; much smaller, suborbicular leaflets up to 2.5 cm in diameter may occur alternating with the normal leaflets. Inflorescence a terminal, drooping, much-branched, many-flowered panicle up to 60 cm × 30 cm, yellowish, often bright red tinged; branches villous to long silky hairy, sticky, subtended by leafy bracts, rachis usually zigzag. Flowers unisexual, regular; pedicel up to 3.5 mm long, densely hairy, subtending bracts clasping the pedicel at base, bracteoles reniform; hypanthium a conical, silky hairy tube 2–3 mm long, with 2 whorls of (4–)5 green or reddish tinged lobes (epicalyx and calyx), in male flowers epicalyx lobes smaller than calyx lobes, in female flowers larger and enlarging up to 10 mm long in fruit; petals (4–)5, vestigial, up to 1.5 mm long, alternating with the calyx lobes; stamens 15–20, filaments up to 3 mm long in male flowers, in female flowers rudimentary; pistils usually 2, free within the hypanthium, ovary with a tuft of hairs at top, style subfiliform, stigma capitate, usually only one ovary per female flower developing to fruit, in male flowers functionally sterile. Fruit a globose to ovoid achene up to 2.5 mm in diameter, with a thin, papery, pale to brown pericarp, white-hairy at top, enclosed by the dry persistent hypanthium with the epicalyx serving as wings. Seed subglobose to subovoid, only slightly smaller than the fruit, usually with a wrinkled, brown, glabrous testa.




*Hagenia abyssinica – 1, part of flowering branch; 2, female flower; 3, male flower; 4, fruit. Redrawn and adapted by M.M. Spitteler.*

**Other botanical information** *Hagenia* is monotypic and very characteristic with its dioecism, pinnate, silky leaves and large, drooping inflorescences.

**Anatomy** Wood-anatomical description:
– Macroscopic characters:
Heartwood dark red to red-brown, indistinctly demarcated from the creamy-yellow sapwood which may be up to 5 cm wide. Grain straight or interlocked. Texture fine. Growth rings indistinct. Radial surface sometimes with slight silver grain figure.
– Microscopic characters:
Vessels diffuse, 5–8/mm$^2$, solitary or in radial pairs, sometimes clustered; perforations simple. Parenchyma absent or indistinct. Rays 1–2/mm, broad, up to 1.5 mm high, homocellular or heterocellular with 1–2 rows of square cells. Gummy deposits abundant.

**Growth and development** Individual *Hagenia abyssinica* trees often belong to the same or only a few size classes and are presumably the same age. It has been assumed that *Hagenia abyssinica* has a regeneration cycle associated with heavy forest fires. Crucial factors for seed germination are high temperatures and bare soil.

Fire promotes germination by clearing the area of competitive plants and heating the prospective seedbed. Mature *Hagenia abyssinica* trees are tolerant of fire, and heavy fires create ideal germination conditions for the small wind-dispersed seeds. *Hagenia abyssinica* is unable to regenerate in areas suffering from a high level of grazing. Young trees have poor competitive ability.

Individual trees are either male or female, but sometimes polygamous. In Ethiopia, flowering occurs during the dry season between October and February; on sunny days the flowers are much visited by bees.

**Ecology** *Hagenia abyssinica* occurs in montane rain forest and evergreen bushland, at altitudes of (2000–)2400–3400(–4300) m where annual rainfall ranges between 1000–1600 mm. On Mt. Kenya, it is dominant in the zone above bamboo thickets, between 2900–3400 m, where it occurs in association with *Hypericum revolutum* Vahl, *Juniperus procera* Hochst. ex Endl. and *Gnidia glauca* (Fresen.) Gilg. At these altitudes forest fires are rare, but occasional severe fires can occur during drought. In Ethiopia, *Hagenia abyssinica* is a dominant tree in subhumid montane woodland (rainfall up to 1250 mm per year). In humid montane woodland (rainfall up to 1600 mm per year), it occurs in association with the dominant tree bamboo *Sinarundinaria alpina* (K.Schum.) C.S.Chao & Renvoize, together with *Schefflera volkensii* (Engl.) Harms, *Hypericum* spp., *Ilex mitis* (L.) Radlk. and *Nuxia congesta* R.Br. ex Fresen.

**Propagation and planting** Seed can be stored dry without special requirements for 0.5–1 year. Germination is about 40–60% after 2–3 weeks from sowing. The seed is very light: 400–5-00 seeds per gram. The tree is occasionally planted around churches and villages. Large-scale cultivation is unknown. In agricultural areas, *Hagenia abyssinica* can be found scattered in fields because it is not usually cut down.

**Management** In agroforestry systems in the southern highlands of Tanzania, trees grown or retained for shade are pruned once a year, about 50% of the foliage being removed.

**Harvesting** Inflorescences are collected mainly from the wild, dried and stored, and can be used throughout the year.

**Yield** No yield data are available. Only small numbers of flowers are needed per treatment; wild populations of *Hagenia abyssinica* easily provide the necessary quantities.

**Handling after harvest** The powdered flowers are soaked overnight in water, honey-beer, or other sweetened fluids, to counteract the bitter taste. In Ethiopia, kosso is often taken with other plants to render its action more agreeable, e.g. with *Malva verticillata* L. (all parts), *Linum usitatissimum* L. (seeds) or *Zehneria scabra* (L.f.) Sond. (whole plant), or mixed with other anthelmintic plants, e.g. *Phytolacca dodecandra* L'Hér. (fruits and roots), *Croton macrostachyus* Hochst. ex Delile (bark) and *Olea europaea* L. (leaves).

**Genetic resources** *Hagenia abyssinica* is widely distributed in montane Africa and not endangered. Collection of inflorescences for medicinal purposes does not greatly affect the plants. However, in locations with high population and cattle pressure the species is now rare or has disappeared (often cut for firewood purposes). No germplasm collections are known. Living collections and other conservation measures are strongly recommended.

In the southern highlands of Tanzania, *Hagenia abyssinica* is a protected tree. A royalty fee is required for a licence to exploit it. Consequently, few trees have been planted since the mid-1980s when the laws were more strictly enforced – an unfortunate result of well-intentioned conservation laws.

**Prospects** It is difficult to predict the medicinal future of *Hagenia abyssinica*. As long as tapeworm infestation occurs in remote areas (e.g. in Ethiopia) only equally cheap substitutes will reduce the use of kosso. In the long term, the crude drug will disappear from use as a result of restrictions on use. Commercial kosin extraction from flowers depends on quality, demand and price. Pharmacological research is underway in Ethiopia. *Hagenia abyssinica* is worthy of protection and worth planting for its ornamental value.

**Major references** 2062, 3811, 5180, 5546, 5547, 5548, 5549

**Other references** 5550, 5551, 5552, 5553, 5554, 5555, 5556, 5557, 5558, 5559, 5560, 5561, 5562, 5563, 5564, 5565, 5566, 5567, 5667

**Sources of illustration** 2062

**Authors** P.C.M. Jansen & Getachew Aweke

## INDIGOFERA ARRECTA Hochst. ex A.Rich.

**Protologue** Tent. fl. abyss. 1: 184 (1847).

**Family** Papilionaceae (Leguminosae - Papilionoideae, Fabaceae)

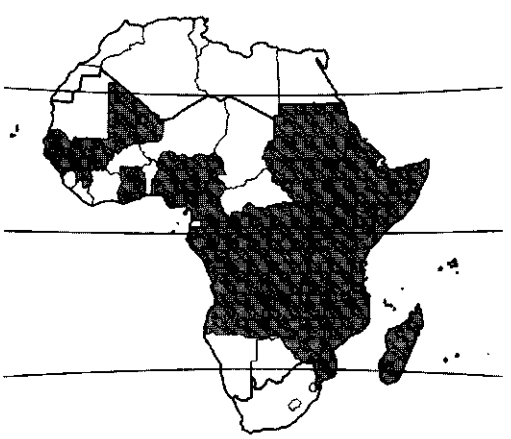
**Chromosome number** $2n = 16$

**Vernacular names** Natal indigo, Bengal

indigo, Java indigo (En). Indigotier, indigotier chessé (Fr). Indigueiro, anileira (Po). Mnili (Sw).

**Origin and geographic distribution** Natal indigo originates from Africa. It occurs almost throughout tropical Africa, and also in South Africa (Transvaal, Natal), Swaziland and southern Arabia. Its range has probably been extended considerably due to cultivation. It is widely planted in India and south-eastern Asia (Laos, Vietnam, the Philippines and Indonesia). In Africa, it has been the most important species for the production of indigo since the beginning of the 20th Century.

**Uses** Natal indigo is a source of the blue dye indigo, which is used for dyeing textiles dark blue to almost black. Indigo has been called 'the king of dyes', and no dye plant has been as closely combined with culture as the indigo plant. The deep blue colour of the dye has long been highly appreciated, and its history is remarkable, going back thousands of years. In western Africa, indigo is by far the most important dye of plant origin. It plays an important role in traditional cultures of tribes in northern Senegal, the Tuareg in the Sahara and Sahel region (Niger, Mali), the Dyula tribe in Côte d'Ivoire, and the Yoruba and Hausa tribes in Nigeria. However, traditional uses are rapidly declining or have disappeared completely. Nowadays, indigo of synthetic origin is almost exclusively used, usually only in industrialized processes. In Indonesia, indigo is used in the batik process, where wax is used to construct a pattern in textile by protecting certain patterns or designs from the watery solution of the dye. In Central America, indigo was one of the products used for dyeing traditional clothes, e.g. by the Maya people and their descendants, while in the United States it was the original dye used for blue jeans.



*Indigofera arrecta – wild.*

Natal indigo is grown as a cover crop and for green manure, especially in tea, coffee, and rubber plantations. It gives shade and protection, suppresses weeds and improves the soil. The residue remaining after indigo extraction is considered a good manure. In Malawi, the young leaves are eaten as a vegetable. The plants are grazed by all stock.

Numerous applications in traditional medicine have been reported: leaves and roots are used externally to treat itching and in an infusion or decoction as an anti-spasmodic, sedative, stomachic, febrifuge, vermifuge, abortive, diuretic and purgative, e.g. to treat gum infections, snake bites, gonorrhoea, epilepsy and jaundice; the fruits and seeds are used to treat ophthalmia. In Ghana, an aqueous extract of leaves from immature shoots is administered orally to patients with diabetes mellitus. A medicine for the management of peptic ulcer and methods of its preparation and use have been patented. In several regions in Africa, it is believed that the indigo in clothes prevents skin affections. In East Africa, the twigs are used for cleaning teeth.

**Production and international trade** The use of dye from *Indigofera* species has a long history. Indigo plants and their products have even been mentioned in the oldest Sanskrit records. The blue dye used for textiles of Egyptian mummies could be from *Indigofera*. In Antiquity, indigo used to come to the Mediterranean region by trade from India. Large-scale cultivation of *Indigofera* started in the 16th Century in India and south-eastern Asia. Later, large plantations were established in Central America and the southern United States. The large-scale export of indigo from Asia to Europe started in about 1600 and had to compete with dye from woad, *Isatis tinctoria* L., which was cultivated mainly in France, Germany and Great Britain. By the end of the 17th Century, indigo had almost completely replaced woad. Synthetic indigo, which came into commercial production in 1897, proved catastrophic to the production of natural indigo, and by 1914 only 4% of the total world production was of vegetable origin. Later, most synthetic indigo was replaced by other synthetic dyes, such as alizarin dyes, which are more durable. The popularity of blue jeans with their imperfect, superficial colouring revived the interest in indigo.

At present, the crop is still cultivated for dye on a very small scale in India and in some parts of

Africa, southern Arabia (Yemen), Central America and Indonesia. The most important present-day centre of indigo production from *Indigofera* is probably the northern part of Karnataka state in India.

**Properties** *Indigofera* plants contain the glucoside indican. After soaking the plants in water, enzymic hydrolysis transforms indican into indoxyl (indigo-white) and glucose. Indoxyl can be oxidized to indigotin (indigo-blue). The indigotin content of leafy branches is 0.8–1.0%. Indigotin is insoluble in water, so to dye textiles it must be reduced to a soluble form by a fermentation process under alkaline conditions. Subsequent oxidation results in the blue colour of the textile. Natural indigo contains varying proportions of a chemically related red dye called indirubin.

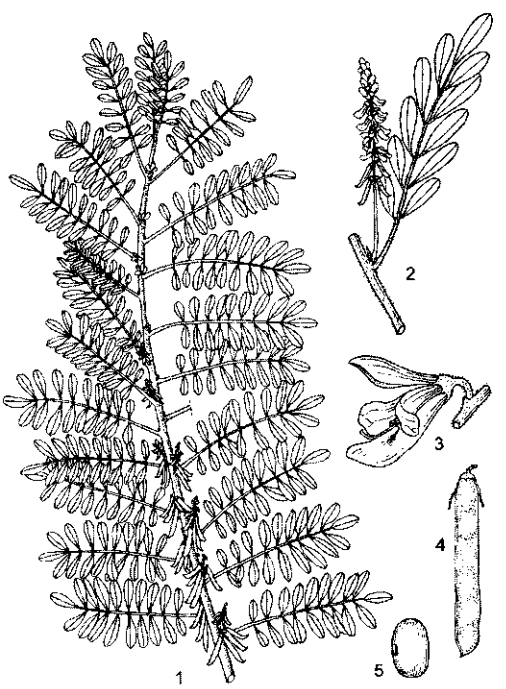
An aqueous extract prevented the development of hyperglycaemia in genetically obese diabetic mice. In tests with rats, an intraperitoneal administration of a hot water extract of dried leaves decreased the plasma glucose levels of fasting normoglycaemic rats, but did not prevent the rise in plasma glucose after an oral glucose load. It was suggested that the extract is insulinotropic and may require functional β-cells to be active.

In tests with healthy, non-diabetic, young adult male volunteers in Ghana, an extract of Natal indigo increased the erythrocyte sedimentation rate and decreased lymphocyte concentration in the blood. It did not alter the mean systolic and diastolic pressures, nor did it change fasting blood glucose, whereas serum marker enzymes and metabolites for hepatic and renal functions remained normal. These data suggest that the species may not have overt toxic reactions but could affect the immune status of users. The extract also showed no acute and subchronic toxic effects in tests with mice.

The leaves contain 4.46% N, 0.02% $P_2O_5$, 1.95% $K_2O$ and 4.48% CaO. Whole plants of Natal indigo showed good palatability in sheep.

**Adulterations and substitutes** Several other, often unrelated, plant species are sources of blue dyes. Examples include: woad, *Isatis tinctoria* L. (*Brassicaceae*) from Europe; *Polygonum tinctorium* Aiton (*Polygonaceae*) from China; Assam indigo, *Strobilanthes cusia* (Nees) Kuntze (*Acanthaceae*) from Indo-China and Thailand; and *Marsdenia tinctoria* R.Br. (*Asclepiadaceae*) from tropical Asia. Yoruba indigo, *Lonchocarpus cyanescens* (Schumach. & Thonn.) Benth. (*Papilionaceae*) is important for West Africa; it also contains indican, which can be hydrolyzed and oxidized to indigo-blue of good quality. It is said that when it is mixed with Natal indigo a much superior dye is obtained. This practice is common in dyeing clothes dark blue among the Yoruba tribe in southern Nigeria. Other natural sources of indigo are a mutant of the fungus *Schizophyllum commune*, and the purple snail (*Murex* sp.) contains indigo and a bromine-derivative of it, which together give the famous purple of antiquity. The most important substitute of natural indigo, however, is the industrial product.

**Description** Stout herb, woody at base, or subshrub up to 200(–300) cm tall; stems slightly ridged, rather densely whitish or brownish strigulose with 2-branched hairs. Leaves arranged spirally, imparipinnate; stipules subulate-setaceous, 2–9 mm long; petiole up to 1.5 cm long, pulvinate; rachis up to 6 cm long, strigulose; stipels subulate, up to 1 mm long; petiolules ca. 1 mm long; leaflets 7–21, narrowly elliptical-oblong, up to 2 cm × 0.7 cm, usually glabrous above and strigulose below. Inflorescence a many-flowered axillary raceme up to 5 cm long but usually much shorter, often sessile; bracts lanceolate, ca. 1 mm long, caducous. Flowers bisexual, zygomorphic; pedicel ca. 1 mm long, strongly




*Indigofera arrecta – 1, flowering and fruiting branch; 2, part of stem with leaf and inflorescence; 3, flower; 4, fruit; 5, seed.*
*Redrawn and adapted by W. Wessel-Brand.*

reflexed in fruit; calyx ca. 1.5 mm long, the tube about as long as the 5 triangular lobes, brownish strigulose; corolla ca. 5 mm long, pinkish or reddish, brown strigulose outside, standard longer than wide, narrowed gradually to the base, keel laterally spurred, wings with very short claws; stamens 10, 3–4 mm long, upper filament free, the others united, anthers dorsifixed, apiculate; ovary superior, 1-celled, with long style. Fruit a linear pod 12–17 mm long and ca. 2 mm wide, straight, slightly tetragonal, brown when ripe, 4–6-seeded. Seeds shortly oblong, rhombic in cross-section. Seedling with epigeal germination, cotyledons thick, short-lasting.

**Other botanical information** *Indigofera* is a very large genus comprising approximately 700 species, and is distributed throughout the tropics and subtropics of Africa, Asia and the Americas. Africa and the southern Himalayas are richest in species. Over 300 species have been recorded for tropical Africa.

Some other species have been cultivated for indigo production, especially *Indigofera tinctoria* L., which originates from tropical Asia but is now distributed pantropically, and *Indigofera suffruticosa* Mill., originating from tropical America and now locally cultivated elsewhere in the tropics. The origin and identity of *Indigofera* plants cultivated for dye production is often obscure as a result of introduction, selection and the close affinity of species. *Indigofera arrecta* is sometimes difficult to separate from *Indigofera tinctoria*. The latter usually differs in its larger and less numerous leaflets and longer fruits containing more seeds. In East Africa, but not in West Africa, *Indigofera arrecta* generally occurs at higher altitudes than *Indigofera tinctoria*. *Indigofera suffruticosa* is also closely related. Intermediate specimens between these 3 species have been found, possibly of hybrid origin.

**Growth and development** Plants may flower 3 months after sowing. Like many other leguminous plants, Natal indigo forms root nodules with nitrogen-fixing capacity.

**Ecology** Natal indigo occurs in open deciduous forest, upland evergreen bushland, often in forest margins, and secondary regrowth. Its altitudinal range is 200–2700 m, in regions with an annual rainfall of 400–1800 mm. The plant is deep-rooting and withstands drought well. When used as a cover crop, Natal indigo can only be grown in gardens or plantations with little or no shade. An established crop can withstand very wet soil for up to 2 months.

**Propagation and planting** Propagation is usually by seed. Seed yields of 675–1200 kg/ha have been reported for India. The seeds have a hard seedcoat and must be scarified. Land is prepared by ploughing or by hoeing. Sowing is done either in seed-beds or directly into the field, 3–4 seeds per hole, 60 cm apart within rows and 45–60 cm between rows. Germination takes about 4 days. When seed-beds are used, seedlings are transplanted at 4–6 weeks.

**Management** Weeding and earthing up is done about 1 month after planting and again 1 month later. As a cover crop, Natal indigo is slashed at regular intervals. Recovery from slashing is generally better than in *Crotalaria* species, which are commonly used as a cover crop and green manure. Production of seed is usually poor in plants that have been cut. Seed production therefore requires plants to be grown specifically for this purpose.

**Diseases and pests** Natal indigo is attacked by *Ralstonia solanacearum* (synonym: *Bacillus solanacearum*), several fungi and nematodes.

**Harvesting** Branches are harvested when the plants are 4–5 months old and have formed a closed stand. This is usually the flowering stage. About 2–4 months later the plants can be cut again; three crops can be harvested a year. The total lifespan for dye crops is 2–3 years, and 1.5–2 years for cover crops.

**Yield** The dye yield from Natal indigo is higher than from any other *Indigofera* species. Annual yields of 22–100 t green matter per ha have been reported in India; the recorded output of indigo is 135–325 kg/ha per year.

**Handling after harvest** The harvested branches are often pounded to a soft pulp and made into balls, which are sold on the market after drying. For the preparation of indigo, these balls are pulverized in a tank or pit containing water, to which some lime has been added and which is stirred for aeration. The branches can also be placed in such a tank immediately after harvesting. After some hours of fermentation, during which enzymic hydrolysis leads to the formation of indoxyl, the liquid is transferred to another pit or tank and stirred continuously for several hours to stimulate oxidation of the indoxyl to indigo. Afterwards, the solution is left to rest and the insoluble indigo settles to the bottom as a bluish sludge. The water is drained off, and after the indigo has dried it is cut into cubes or made into balls.

To dye textiles, indigo is reduced to a soluble form by a fermentation process under alkaline conditions. In traditional preparations of the dye,

various reducing agents such as molasses are used, together with e.g. coconut-milk, banana and guava leaves. The alkalinity is maintained by adding lime. In industry, an alkaline solution of sodium hydrosulphite is used for the reduction of indigo to indigo white. Often a gum (e.g. from *Acacia senegal* (L.) Willd. or *Anogeissus leiocarpa* (DC.) Guill. & Perr.) is added to make the coloured textile more durable and wind-proof. After the textile has been dipped into the solution of indigo white, it turns blue when exposed to the air. Several dips are needed to impart a dark blue colour to the textile and especially to cotton fabrics, each dip followed by exposure to the air for some time. Dyeing with indigo (as the darkest tinge) is usually the first step in dyeing textiles with complex patterns and different colours, such as batik. Rubbing textiles dyed with indigo makes them paler, but the colour is fairly resistant to soap.

**Genetic resources** Natal indigo is widespread in Africa and is unlikely to be liable to genetic erosion. The share of related species in the gene pool of plants cultivated as *Indigofera arrecta* is unclear, as is the influence of these species and of cultivated plants on the genetic variation of wild-growing *Indigofera arrecta*. Several germplasm collections of *Indigofera* exist, the largest being maintained at CSIRO, St. Lucia, Queensland, Australia (365 accessions) and CIAT, Cali, Colombia (250 accessions). In Africa, collections are present in Ethiopia (ILRI, Addis Ababa, 60 accessions), Kenya (e.g. National Genebank of Kenya Crop Plant Genetic Resources, Kikuya, 40 accessions half of which *Indigofera arrecta*) and in South Africa (Pretoria).

**Prospects** In spite of its cultural importance, the use of indigo of vegetable origin has almost disappeared, being replaced by synthetic indigo. In West Africa, coloured textiles which were, and are, an important element of the cultural heritage, are nowadays often imported from Asia or Europe. In recent years, interest in natural dyes has been increasing in many countries, as a result of concern about environmental pollution caused by dye-producing chemical industries, and because of a revival of interest in the relation between dyes and culture. Hopefully this new interest will gain ground rapidly enough to prevent indigo of plant origin from disappearing completely. Natal indigo is a multipurpose species; it is very useful as a forage and as a cover crop and green manure in agriculture, and the medicinal properties deserve more research.

**Major references** 2107, 5406, 5407, 5408, 5409, 5410, 5411, 5412, 5414, 5416

**Other references** 5413, 5415

**Sources of illustration** 5405 (flowering and fruiting branch, fruit), 5409 (part of stem with leaf and inflorescence, flower, seed)

**Authors** R.H.M.J. Lemmens

## KIGELIA AFRICANA (Lam.) Benth.

**Protologue** Hook., Niger Fl.: 463 (1849).

**Family** Bignoniaceae

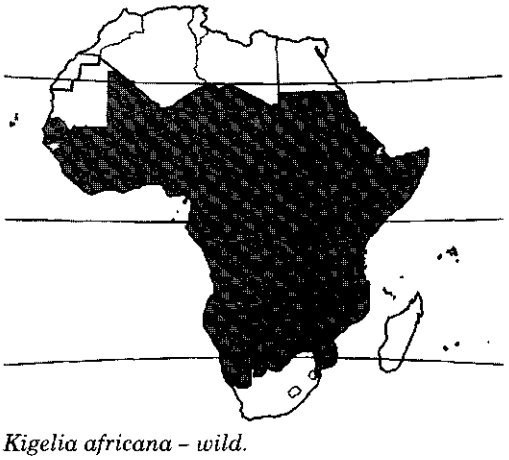
**Chromosome number** $n = 20, 21, 2n = 40$

**Synonyms** *Kigelia aethiopica* Decne. (1845), *Kigelia pinnata* (Jacq.) DC. (1845).

**Vernacular names** Sausage tree, cucumber tree (En). Saucissonnier, faux baobab (Fr). Mvungunya, mwegea, mwicha, mranaa (Sw).

**Origin and geographic distribution** *Kigelia africana* occurs throughout tropical Africa, particularly in the drier regions. It is also found in South Africa (Northern Province, Kwazulu-Natal) and Swaziland, but does not occur in Mauritania, São Tomé and Principe, or the Indian Ocean islands. It has been introduced as an ornamental to Cape Verde and Madagascar, as well as to Iraq, Pakistan, India, China, South-East Asia, Australia, Hawaii and Central and South America.

**Uses** *Kigelia africana* is widely used throughout Africa for a variety of purposes, particularly in local medicine, and more recently in commercial applications to treat various skin complaints. The diversity of complaints against which the plant is used includes fainting, anaemia, sickle-cell anaemia, epilepsy, respiratory ailments, hepatic and cardiac disorders, and nutritional



*Kigelia africana* - *wild.*

illnesses such as kwashiorkor, rickets, wasting and weakness. The leaves are sometimes used to prepare a general tonic for improved health and growth. Aqueous fruit preparations are applied as a wash or rub to promote weight gain in infants. The roots, bark, leaves, stems, twigs and fruits are used to treat digestive disorders. Administration is typically by oral ingestion or as an enema. The roots, bark and ripe or unripe fruits are taken as a laxative or emetic, to treat chronic and acute digestive disorders and against gastric infections. Remedies containing the fruits of *Kigelia africana* and *Capsicum* or *Anthocleista* are taken internally to relieve constipation or haemorrhoids.

Infections of the genito-urinary tract, particularly venereal diseases, are treated both internally and externally with preparations of the roots, bark, leaves, stems and twigs. In West and Central Africa, palm wine, in which dried and ground bark is macerated, is taken against syphilis. Venereal diseases in children are treated simultaneously with a drink and wash prepared from decocted bark. A commercial product containing *Kigelia africana* stem bark is used to treat *Candida albicans* infections. In Côte d'Ivoire, renal and bladder ailments are treated with medicaments containing the bark and leaves of *Kigelia africana* and several other medicinal plants.

*Kigelia africana* is widely used to treat gynaecological disorders. Aqueous preparations of the roots, fruits and flowers are administered orally or as a vaginal pessary. The fruits and bark are used to promote breast development in young women, or in contrast to reduce swelling and mastitis of the breasts. The fruits are further employed as a galactagogue. The bark and leaves are decocted and administered as an abortifacient.

Sexual complaints such as infertility, poor libido, sexual asthenia and impotence are treated with medicines containing the fruits, roots or leaves. A small amount of unripe fruit is chewed, or an aqueous preparation is taken orally as a sexual stimulant, and the intoxicating traditional beer to which they are added is drunk as an aphrodisiac. Excessive use of *Kigelia africana* to treat male sexual complaints is said to induce scrotal elephantiasis, although in some regions the fruits are used to remedy this condition.

Powders and infusions of the bark, leaves, stems, twigs or fruits are used to clean and dress flesh wounds and open sores. Many dressings, topical treatments and infusions containing *Kigelia africana* are also used for their analgesic and anti-inflammatory properties. The bark, stems, twigs, leaves and fruits are infused and taken orally, or applied locally, to relieve rheumatism, sprains, haematoma and bruising; a decoction of the fruit and bark is used to relieve toothache and headache. Snake bite antidotes are made with an infusion of the fruits, stems, leaves, twigs or bark, taken orally or rubbed onto the bite. A fruit decoction is used to treat oedema of the legs.

*Kigelia africana* is used to treat infectious diseases including leprosy, impetigo, and worm infestations in the blood. Dermal complaints and infections, such as whitlows, cysts, acne and boils, are treated with traditional medicines containing the fruits, and less frequently, the bark. Sore eyes are treated with drops made from flower sap mixed with water. Commercially manufactured products are used for symptomatic relief or cure of skin conditions including, among others, sunburn, chafing, psoriasis, itchy scalp and nappy rash. A broad-spectrum antimicrobial cream, reputedly effective against a number of common microbial infections, is produced from the stem bark. Fungal infestations such as ringworm, mycosia and athlete's foot are washed with the water in which bark has been macerated, and preparations containing the leaves and fruits applied locally. A root decoction is administered against internal parasitic infestations, notably tapeworm.

*Kigelia africana* is used in both traditional and orthodox medicines to treat malignant neoplasms such as skin melanoma, tumours and breast cancer. Traditional preparations include extracts, poultices and powders of the bark or fruits; topical creams containing extracts of the fruits are produced commercially.

The fruits, and sometimes other plant parts, are also much used in ethnoveterinary medicine to treat digestive system disorders, leg oedemas, dermal irritations and infections, mastitis and retained placenta. Brucellosis and Newcastle disease are also treated with *Kigelia africana*.

*Kigelia africana* provides a nutritious food source during times of famine: the hard seeds are roasted and eaten. The fruit pulp, however, is said to be inedible and toxic, may have intoxicant or purgative effects, and may cause blistering of the tongue and skin. However, fallen fruits along with leaves and flowers are browsed or foraged by livestock and game. Fruits and bark are used in the brewing process to aid fermentation and enhance the flavour of traditional beers, often mixed in variable proportions with roots of *Aloe* spp.

The wood is considered excellent for dugout canoes, planks and fence-posts. It is also used for making boxes, drums, stools, yokes, tool handles, mortars and large bowls for watering cattle. Weapon bows are made from branches, and smaller branches are hollowed to administer enemas to children. Wood and fruits are carved into mousetraps, dolls, and various items of crockery and cutlery. The wood is used as fuel. A black dye is obtained from the tannin-rich fruit pulp.

Due to the unusual fruits and large flowers, *Kigelia africana* is considered a striking ornamental plant, and the fruits are used as florists' material. The thick stem is an attractive feature for bonsai. The tree is sometimes planted as a boundary marker, but usually at roadsides and for shade. Due to its occurrence along watercourses, it is suitable for erosion control and riverbank stabilisation.

*Kigelia africana* is regarded as sacred in many regions; religious meetings are held underneath the tree, and the flowers and fruits are regarded as fetish. Fruits are commonly sold in markets as charms to promote wealth and prosperity, to impart strength and courage on warriors prior to battle, to increase crop yields, and as a fetish for fecundity, or to avert whirlwinds.

**Production and international trade** *Kigelia africana* is of subsistence value in most parts of Africa; the fruits and bark are collected and traded locally in market places. Commercial value is attributable to industrially produced pharmaceutical products, for which fruits are harvested from naturally occurring trees, and stem bark from young cultivated trees in Zimbabwe.

**Properties** The use of *Kigelia africana* in traditional African medicines is in some cases verified by corresponding pharmacological properties. Of the phytochemicals elucidated in extracts of *Kigelia africana*, the compound groups to which activity is most frequently attributed are naphthoquinones and iridoids.

Extracts of the bark, wood, roots and fruits possess antibacterial and antifungal properties. These extracts exhibit significant inhibitory effects *in vitro* against common Gram-negative and Gram-positive bacteria, and the yeast *Candida albicans*. Of the naphthoquinones isolated in fruit and root extracts, kigelinone has shown notable antimicrobial activity. Iridoids and dihydroisocoumarins in extracts of the bark, fruits and roots may enhance the antimicrobial activity of naphthoquinones. Other active antimicrobial compounds present in the bark and fruits are the phenylpropanoids caffeic acid, *p*-coumaric acid and ferulic acid. The naphthoquinones are responsible for the antiprotozoal activity of root bark against trypanosomes.

*Kigelia africana* is renowned for anti-cancer properties, and laboratory screening has confirmed *in-vitro* anti-cancer activity. Fruit extracts exhibited significant effects against induced tumours in mice. Fruit and bark extracts have shown moderate efficacy against melanotic cell lines. Extracts of dried fruit elicited lower cytotoxic responses than those of fresh fruit, indicating that the active principles may be thermolabile. The naphthoquinones lapachol and isopinnatal, elucidated in some extracts of bark, wood, fruits and roots, exhibit antineoplastic activity against melanoma cell lines. Sterols and iridoids are ubiquitous in the plant and may be a factor in the activity against melanoma. Naphthoquinones and sterols isolated in root extracts suggest anti-cancer potential, although *in-vitro* activity is not confirmed. The reported cytotoxicity of the root bark in the brine shrimp assay was attributed to the presence of γ-sitosterol.

The use of fruits for anti-inflammatory purposes is supported by effects against inflammation induced in rat paws. Cinnamic acid derivatives are thought to be responsible for anticonvulsant properties for which *Kigelia africana* is used to prevent epileptic fits.

The leaves and fruits contain flavonoids. A high concentration of flavonoids may be responsible for antidiarrhoeal properties, increased by antimicrobial constituents. In contrast to the use of *Kigelia africana* as a laxative, preliminary studies have shown a preventive effect of leaf extracts against diarrhoea in laboratory rats.

The bark and leaves are bitter tasting, and the bark is reported to contain a bitter principle. Acute toxicity tests of the fruits indicate they are non-toxic, although they are said to be very poisonous. Tannins present in the bark and fruit impart a dark, astringent dye. Sap from the fruits may temporarily stain the hands brown.

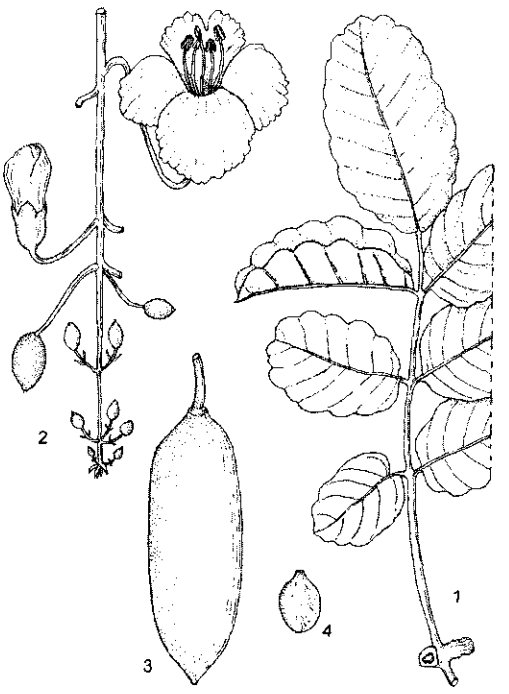
The wood is whitish or yellowish with pale brown to reddish-yellow heart, moderately heavy (about 720 kg/m$^3$ at 15% moisture content), easy to work and takes a good polish. However, it is not of commercial value. Its energy value is 15–17 MJ/kg.

**Description** Small to medium-sized, semi-deciduous tree, up to 25(–35) m tall; trunk up to 60 cm in diameter, widely and low branching; bark grey, smooth or flaking; crown rounded.

Leaves opposite or whorled, usually in whorls of 3, usually crowded towards the apex of branches, imparipinnate, up to 60 cm long; stipules absent; petiole up to 15 cm long, rachis up to 25(–29) cm long; leaflets 5–13, lateral ones subopposite, subsessile except terminal leaflet, ovate, elliptical, obovate to rounded, 3.5–17.5(–22.5) cm × 2.5–11 cm, base rounded to cuneate, more or less asymmetrical, apex rounded or retuse to broadly tapering, margin entire, serrate, toothed or wavy, papery to leathery, glabrous to more or less hairy at both surfaces, with (4–)6–13 pairs of lateral veins. Inflorescence a terminal, pendulous, very lax panicle, up to 100(–150) cm long, with long peduncle. Flowers bisexual, very large; pedicel up to 11(–13.5) cm long, upcurved at tip; calyx shortly tubular to campanulate, 2–4.5 cm long, irregularly 4–5-lobed; corolla widely cup-shaped, 6–12 cm long, tube cylindrical at base and suddenly widening and incurving upwards, limb 2-lipped, the superior lip 2-lobed, the lower one 3-lobed and recurved, lobes rounded, at first yellowish, later becoming reddish to purplish with darker streaks; stamens 4, didynamous, adnate to the corolla tube, 4–7.5 cm long, staminode 1; disk annular, thick; ovary superior, 1-celled, up to 1.5 cm long, with 2 parietal placentas, style filiform, up to 7 cm long. Fruit a large, sausage-like, pendulous berry up to 100 cm × 18 cm and up to 12 kg in weight, with peduncle up to 100 cm long, indehiscent, wall woody, surface heavily marked by lenticels, grey-brown when mature, many-seeded. Seeds obovoid, ca. 10 mm × 7 mm, testa leathery, embedded in a fibrous pulp.

**Other botanical information** *Kigelia africana* is extremely variable in habit and leaf morphology. This has led to the distinction of up to 10 separate species. Nowadays, it is generally accepted that *Kigelia* comprises a single polymorphous species. Despite the present recognition of only one species, synonyms are continually used in the literature. Specimens growing in the forest tend to have larger leaflets with more acute apices, entire margins and dense indumentum compared with specimens from the savanna. Recent studies maintain at least two sub-generic taxa in East Africa, occupying overlapping savanna- and forest vegetation types.

**Anatomy** Wood-anatomical description:
– Macroscopic characters:
Heartwood pale brown to reddish-yellow.
– Microscopic characters:
Growth rings usually indistinct. Vessels diffuse, ca. 11/mm², mostly solitary but also in irregular multiples of 2–3, with an average tangential diameter of 150 µm; perforation plates simple; intervessel pits with an average diameter of 8 µm; vessel-ray pits simple; tyloses sometimes present. Fibres sparse, thin- to thick-walled, non-septate, on average ca. 980 µm long, with distinctly bordered pits. Parenchyma exceptionally abundant, both as paratracheal and as banded parenchyma. Rays ca. 7/mm, but 4/mm also recorded, (2–)3–4 cells wide, all ray cells procumbent although the marginal cells are somewhat shorter and slightly higher than the body ray cells; storied structure absent.




*Kigelia africana – 1, leaf; 2, part of inflorescence; 3, fruit; 4, seed.*
*Redrawn and adapted by W. Wessel-Brand.*

**Growth and development** In warmer regions, the growth rate of young plants can exceed 1 m/year, and the tree will reach good shade proportions within 5 years. In colder climates, germination and vegetative growth are relatively slow. The flowering period for a single tree continues for several months. Flowers open in the evening, and remain open for one night only. The corolla falls off within 2 days, leaving the persistent calyx, ovary and style. Pollination studies suggest that the most important pollination vectors are bats. However, unlike most bat-pollinated flowers which are characteristically white or cream, the

flowers of *Kigelia africana* are reddish to purplish; the strong unpleasant odour is likely to be the primary attractant.
Fruits may remain on the tree for up to 6 months. Seed is released only on decay of the fallen woody fruits, or dispersed when eaten by game and livestock. Elephant and rhinoceros are reported as seed distributors.

**Ecology** *Kigelia africana* occurs along watercourses, in riverine fringes, alluvial and open woodland, high-rainfall savanna, shrubland, and in rain forest. It occurs on loamy red clay soils, sometimes rocky, damp or peaty, from sea level up to 3000 m altitude.

**Propagation and planting** *Kigelia africana* is readily propagated by seed; vegetative propagation using cuttings is possible but success rates are generally low. It is best grown in warm areas, due to cold intolerance. It is not frost resistant, but young plants will survive if protected for the first three years. In southern Africa it is reputedly quick-growing from seed. In other areas germination rate is poor. It is also propagated by wildings, and hardwood cuttings have been used successfully in experiments. It may be competitive to crops in arid areas where water is limiting. *Kigelia africana* is not a prolific seeder; number of viable seeds per kg fibrous fruit pulp is between 3400 and 9700. Although it is sometimes advised that seed should not be stored, dry seeds store well under cool conditions. Seed storage behaviour is orthodox; viability is maintained for more than 3 years in airtight storage at ambient temperature with 11–15% humidity. Although pre-treatment is not essential, seeds may be soaked in hot or boiling water for 1 minute prior to sowing. Seeds are pressed into seedling trays filled with pure river sand, covered with a shallow layer of sand or compost, and kept moist. Germination commences within 10–25 days.

**Diseases and pests** A rust disease caused by *Newinia kigeliae* has been reported.

**Genetic resources** *Kigelia africana* is not threatened. It is widely distributed and common in many regions. It is considered occasional in Kenya. In Malawi, its value as a wood source for dugout canoes is such that the tree is protected. Studies on the genetic variability are needed to elucidate the wide morphological variation.

**Prospects** Considering the many medicinal purposes for which it is used, there is enormous scope for future research of *Kigelia africana*, and further pharmacological investigation is warranted. Studies focusing on sustainable harvesting and management are necessary, in order to prevent mismanagement of the tree as it becomes increasingly popular commercially. Its potential for erosion control should be investigated.

**Major references** 2054, 2105, 2108, 2177, 5444, 5478, 5479, 5480, 5481, 5482, 5484

**Other references** 3811, 5483, 5486, 5487, 5488, 5489, 5490, 5491, 5492, 5493, 5494, 5495, 5496, 5497, 5498, 5499, 5500, 5501, 5502, 5503

**Sources of illustration** 5287 (fruit, seed), 5478 (leaf, part of inflorescence)

**Authors** O.M. Grace & S.D. Davis

## LYCOPODIELLA CERNUA (L.) Pic.Serm.

**Protologue** Webbia 23: 166 (1968).

**Family** Lycopodiaceae

**Chromosome number** $2n = 312$

**Synonyms** *Lycopodium cernuum* L. (1753), *Lepidotis cernua* (L.) P.Beauv. (1805), *Palhinhaea cernua* (L.) Vasc. & Franco (1967).

**Vernacular names** Stag-horn moss, monkey's paws, nodding club-moss (En).

**Origin and geographic distribution** *Lycopodiella cernua* is found throughout the tropics and subtropics, extending to Japan, the Azores and New Zealand. It occurs throughout Africa, Madagascar and the Mascarene Islands, except in the driest regions.

**Uses** *Lycopodiella cernua* is widely used as an ornamental, both indoors and outdoors. It is also used in floral decoration, to make wreaths and baskets. In tropical America and Asia it has several applications in traditional medicine. In South-East Asia a decoction of the whole plant is used externally as a lotion to treat beri-beri, coughs and asthma, and in embrocations to treat skin eruptions and abscesses. In tropical America it is used as a diuretic, and to treat gout, arthritic swellings, skin irritations, gonorrhoea, leucorrhoea and dysentery. A traditional Chinese medicine is prepared from *Lycopodiella cernua* plants by ultrafiltration. It is administered to treat rheumatism, hepatitis and dysentery, and applied externally to bruises, burns and scalds. There are no records of medicinal applications in continental Africa, although a decoction of *Lycopodiella cernua* is used in Madagascar as a tonic and in a mixture with *Tristemma mauritianum* J.F.Gmel. to treat neuralgia and hypertension. In Micronesia it is used as a cockroach repellent. It is also used to stuff cushions as a kapok substitute.

**Properties** Phytochemical investigations of *Lycopodiella cernua* plants showed the presence of alkaloids such as cernuine and nicotine, the

flavonoid apigenin, apigenin-7-glucoside, the triterpene serratenediol and, as in many other *Lycopodiaceae*, a high concentration of aluminium (up to 12.5% of ash). Tests with rats showed that injection with the traditional Chinese medicine prepared from *Lycopodiella cernua* is effective against experimental silicosis, not only as a prophylactic but also when used to treat the disease.

**Botany** Terrestrial herb with creeping main stem of indefinite length, rooting at long intervals; erect shoots distant, somewhat resembling little pine trees, up to 100 cm tall, basal part simple, distal part with numerous subopposite, highly compound, spreading branches, ultimate branches nodding to pendulous. Leaves arranged spirally, linear-subulate, 2–3(–5) mm × 0.1–0.3 mm, base broadly decurrent, apex sharply pointed, margin entire, pale yellowish or brownish, thick but soft, changing gradually from patent-reflexed and rather distant on the shoot axis to falcately ascending and closely approximate on the ultimate branches. Strobili terminal on the branches, sessile, pending, ovoid to ellipsoid, 3–15(–25) mm × 1.5–3(–5) mm; sporophylls ovate to deltoid, ca. 2 mm × 1 mm, margins coarsely and irregularly laciniate, yellowish or greenish; sporangium subglobose, opening with very unequal valves, concealed by the sporophyll base. Spores globose, with a 3-pronged scar, rugulose. *Lycopodiella cernua* has been placed in the genus *Palhinhaea* on the basis of phytochemical characteristics. However, it is currently accepted that this genus should be treated as a section of *Lycopodiella*, i.e. sect. *Campylostachys*. At least 40 varieties have been described within *Lycopodiella cernua*, most of which are hardly distinguishable.

*Lycopodiella cernua* may produce strobili throughout the year, but may also pass the dry season as buried stem tips while the rest of the plant dies.

**Ecology** *Lycopodiella cernua* occurs along forest fringes, in young secondary forest, often in swamp margins, in grassland (including wet grassland), along roadsides and railways, on moist cliff-faces, hillsides and mountain slopes, up to 2400 m altitude. Locally it is abundant, sometimes as a weed. Although not particularly umbrophile, in southern Africa it is not found in areas with less than 600 mm annual rainfall. It is apparently fire resistant.

**Management** *Lycopodiella cernua* can be propagated by layering of growing tips. Harvesting is done from wild populations when need arises. Fresh stems and branches are tied up into bundles and brought to the market for sale.

**Genetic resources and breeding** *Lycopodiella cernua* is probably the world's most abundant and widespread club-moss, and is therefore not in danger of genetic erosion.

**Prospects** Many aspects of *Lycopodiella cernua* are still unknown. Since this club-moss is in great demand in floriculture, research on its cultivation warrants more attention. More research on pharmacological activity is also desirable, considering its applications in traditional medicine outside Africa and the interesting properties demonstrated for other medicinal *Lycopodiaceae* species.

**Major references** 2108, 5484, 5669, 5688, 5692

**Other references** 5672, 5689, 5690, 5691, 5693, 5694

**Authors** R.H.M.J. Lemmens

## OREOBAMBOS BUCHWALDII K.Schum.

**Protologue** Notizbl. Bot. Gart. Berl. 1(5): 178 (1896).

**Family** Poaceae (Gramineae)

**Chromosome number** $2n$ = unknown

**Vernacular names** Large green bamboo (En).

**Origin and geographic distribution** *Oreobambos buchwaldii* is restricted to eastern and south-eastern Africa, where it occurs scattered in eastern Democratic Republic of Congo, western Kenya, Uganda, Tanzania, Malawi, Zambia and Zimbabwe; perhaps it is also present in South Africa (Northern Provinces).

**Uses** In Malawi the stems are used to make fences for livestock and flat, plate-like baskets. Local people from Northern Provinces (South Africa) fashion ritual flutes from the stems of a bamboo species, possibly *Oreobambos buchwaldii*.

**Botany** Bamboo growing in small dense patches or solitary clumps, with woody, green, hollow culms 4.5–20 m tall and 5–10 cm in diameter, usually spreading or drooping. Leaves alternate, simple; sheath initially covered with appressed, stiff, brownish hairs; blade lanceolate or oblong-lanceolate, 10–35 cm × 2.5–6 cm, acutely acuminate, pale green to slightly bluish-green, with parallel veins, transverse veins very obscure. Inflorescence a large, loose raceme with alternate clusters of spikelets; bracts ovate-elliptical, involucre-like, up to 1.5 cm long. Spikelets lanceolate to oblong-lanceolate, 12–15 mm long, brown, 2-flowered with both florets bisexual;

lower glume absent, upper glume 9–11 mm long, 11–18-veined, lemma broadly ovate to elliptical-ovate, 10–14 mm long, 11–23-veined with transverse veinlets, palea narrower, 8–12 mm long, 5–11-veined; florets with 6 stamens and an ovary, hairy at tip and having a single stigma; lodicules absent. Fruit a crustaceous caryopsis, with a tuft of silky hairs on apex.

*Oreobambos* is monotypic, and seems most closely related to the large genus *Bambusa*, which has its origin in tropical Asia and America. It differs from *Bambusa* mainly in its cupuliform spikelet clusters.

Plants do not flower for many years after establishment. Gregarious flowering has been recorded in the Shire Highlands in Malawi, but in the Usambara Mountains in Tanzania flowering plants can reportedly be found nearly every year. The plants die after flowering.

**Ecology** *Oreobambos buchwaldii* occurs in forest clearings and swampy forest, and along streams, at altitudes of 300–2000 m.

**Genetic resources and breeding** *Oreobambos buchwaldii* occurs scattered and is, as far as known, not planted, and might be liable to genetic erosion. Inclusion in germplasm collections is desirable.

**Prospects** *Oreobambos buchwaldii* is one of the very few indigenous African bamboos. Very little is known about it. More research is needed on cultivation techniques and potential uses.

**Major references** 3808, 3814, 4802, 5153

**Other references** 3813

**Authors** R.H.M.J. Lemmens

## ORYZA GLABERRIMA Steud.

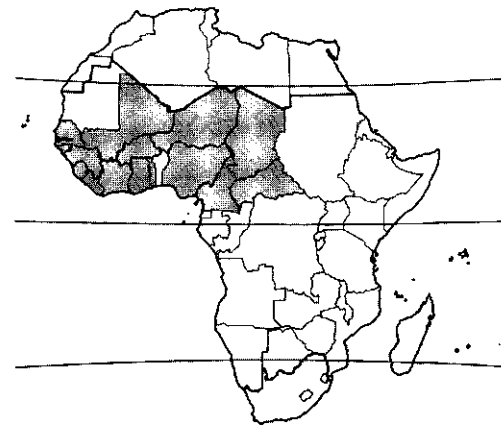
**Protologue** Syn. pl. glumac. 1(1): 3 (1853).

**Family** Poaceae (Gramineae)

**Chromosome number** $2n = 24$

**Vernacular names** African rice, red rice (En). Riz africain (Fr).

**Origin and geographic distribution** *Oryza glaberrima* was probably derived from the wild annual *Oryza barthii* A.Chev. (synonym: *Oryza breviligulata* A.Chev. & Roehr.) around 4000 BC in the Sahara. *Oryza barthii* probably grew abundantly in lakes that existed in this region from 8000–4000 BC. When the climate became drier, it was grown as a rainfed home-garden crop in oases. When the population later took refuge in the interior delta of the Niger (around 1500 BC) and became much larger, *Oryza glaberrima* was transformed into the current floating rice



*Oryza glaberrima - planted.*

crop.

African rice is now grown in a zone extending from the delta of the River Senegal in the west to Lake Chad in the east. To the southeast its range is bordered by the river basins of the Benue, Logone and Chari, but it has also been recorded from the islands of Pemba and Zanzibar (Tanzania). The areas of most intense cultivation of African rice are the floodplains of northern Nigeria, the inland delta of the Niger in Mali, parts of Sierra Leone and the hills on the Ghana-Togo border.

During the slave trade era in the 17th Century, African rice was probably introduced into the New World, where some descendants still cultivate it.

**Uses** In parts of West Africa the grain of African rice is a staple food highly appreciated for its taste and culinary qualities. It is also used in traditional and ritual ceremonies. The finer parts of the bran and broken grains are given as feed to chicken and other livestock. In the Central African Republic, the root is eaten raw to treat diarrhoea.

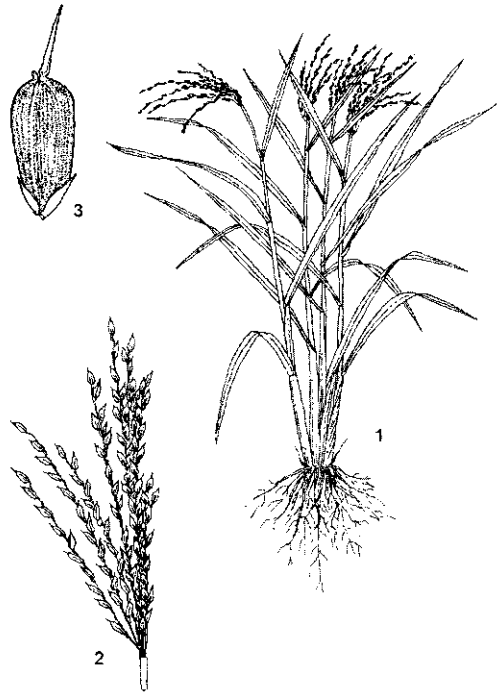
**Production and international trade** In statistics on rice production in West Africa no distinction is made between African rice and Asian rice (*Oryza sativa* L.). It is estimated that African rice is grown in less than 20% of the total area allocated to rice. As a traditional food grain it is not traded internationally, but only within the region of production.

**Properties** The composition of milled African rice varies with cultivar. It averages: protein 7–7.5%, starch 63–80%, cellulose 0.8–1.2%, pectins 1.5%, fat 0.8–2.5%, ash 0.9–6%. In some vitamins and minerals African rice is superior to

Asian rice, e.g. in the important vitamin thiamine and in iron. The degree of gelatinization depends on amylose content, which ranges from 14–30%, and influences consistency of the rice in cooking and thus consumer choice. Most types of African rice are red-skinned. Some cultivars are strongly scented.

**Adulterations and substitutes** In most regions of West Africa, at least in commercial farming, African rice has been replaced by Asian rice, which is considered more productive, scatters less of its seed on the ground and has less brittle grain that is easier to mill. Small-scale farmers often still prefer African rice.

**Description** Annual herb up to 120 cm (–500 cm in some floating types) tall, often cespitose; dryland types with simple culm often rooting at lower nodes, floating types often branching and often rooting at upper nodes too. Leaves alternate, simple; sheath terete, up to 25 cm long, with transverse veinlets; ligule ca. 4 mm long, truncate, membranous; blade linear, flat, 20–25(–30) cm × 6–9 mm, sagittate at base, rugose beneath. Inflorescence a terminal, ellipsoid, stiff and compact panicle up to 25 cm long, with ascendent racemose branches; spikelets ellipsoid, ca. 9 mm × 4 mm, more or less persistent, 3-flowered but 2 lowest florets reduced to sterile lemmas separated from the lemma of the fertile upper floret by a stipe. Flowers bisexual; glumes absent or strongly rudimentary; lemma hispidulous, 5-veined, usually without apical awn; palea 3-veined; lodicules 2; anthers 6; ovary superior, with 2 plumose stigmata. Fruit a laterally compressed caryopsis, up to 9 mm × 3 mm, often reddish, tightly enveloped by lemma and palea.




*Oryza glaberrima – 1, plant habit; 2, inflorescence; 3, spikelet.*
*Redrawn and adapted by W. Wessel-Brand.*

**Other botanical information** *Oryza* comprises about 20 wild species distributed throughout the tropics and subtropics, and 2 cultivated species, *Oryza sativa* and *Oryza glaberrima*. Several approaches to a classification of *Oryza* have been made. The genus has most recently been divided into 3 sections: sect. *Padia*, sect. *Brachyantha* and sect. *Oryza*. Section *Oryza* is subdivided into 3 series: ser. *Latifoliae*, ser. *Australiensis* and ser. *Sativae*. *Oryza glaberrima*, its direct ancestor *Oryza barthii* A.Chev. and the rhizomatous perennial *Oryza longistaminata* A.Chev. & Roehr. are classified in ser. *Sativae*, together with *Oryza sativa*.

**Growth and development** *Oryza glaberrima* has orthodox seeds. Dormancy breaks down with time; storing seed for 5 months results in a germination rate of 80%. After sowing, seedlings emerge in 4–5 days. The vegetative phase of the plant consists of a juvenile phase of about 3 weeks followed by a tillering phase of 3–4 weeks. Vegetative growth is rapid. Tillering, high leaf area index and high specific leaf area contribute to competitiveness against weeds. African rice is self-fertilizing.

Culms tend to be weak and brittle, making African rice prone to lodging. The duration of the crop varies from 3–6 months depending on cultivar. Some cultivars selected for rainfed conditions are of very short duration, shorter than cultivars of *Oryza sativa*. Cultivars for deep water conditions tolerate flooding to 2.5 m deep and culms may grow up to 5 m long. In many cultivars some shattering of seed occurs.

**Ecology** African rice grows well above 30°C, but above 35°C spikelet fertility is noticeably lower. Temperatures below 25°C reduce growth and yield; temperatures below 20°C do so markedly. It is grown from sea-level to 1700 m altitude. African rice is generally a short-day plant, but photosensitivity varies between cultivars from day-neutral to strongly sensitive.

African rice is grown on a wide range of soils. Although preferring fertile alluvial soils, it tolerates low soil fertility. Some cultivars can

produce higher yields than Asian rice on alkaline and on phosphorus-deficient soils. They are also often more tolerant of iron-toxicity. Floating rice is planted on loams or clay soils.

African rice is grown in three cropping systems: upland, floodplain and wet cultivation, depending on rainfall and topography. Upland cultivation depends solely on rain and surface run-off and extends from Senegal to Nigeria and northern Cameroon, where rainfall generally exceeds 1000 mm/year. In some places, short duration cultivars are grown that are adapted to annual rainfall amounts as low as 700 mm/year. Floodplain rice and wet rice depend more on river water than on rainfall and are found in areas with a much drier climate. Floodplain rice on hydromorphic soils is found in Guinea, Côte d'Ivoire, Mali, Burkina Faso and Nigeria. In wet rice cultivation, where the degree of control of irrigation is variable, floating cultivars are grown. Floating rice is very common in the interior delta of the Niger in Mali, and is also planted in Senegal, Gambia, Niger and Nigeria. It grows sometimes very rapidly in length as the flood water rises, tolerating submersion for several days. Along the Atlantic coast, e.g. in Sierra Leone, African rice is grown in mangrove swamps.

**Propagation and planting** African rice is propagated by seed. The weight of 1000 seeds is 20–27 g. Seed dormancy disappears a few months after maturity; for experimental purposes, dormancy can be broken by removing the lemma and palea and about ⅓ of the albumen, allowing germination in 2–3 days.

Seed is mostly broadcast and transplanting is rarely practised. For floating rice, seed is densely sown in soil that has been recently weeded and that may or may not have been ploughed or hoed. Cultivars are selected according to expected flood duration and generally have a growing period of 4–6 months.

In West Africa, African rice is mostly planted as a rainfed crop. In the Senegambia, it is sown in moist places, often under palm trees, after simple soil cultivation. This is locally called 'riz de plateau'. 'Riz de montagne' is grown throughout the forest zone covering western Côte d'Ivoire, Liberia, the Fouta Djallon and eastern Guinea mountains. It is grown in shifting cultivation, often following logging, even on steep slopes. The undergrowth is cut and at the end of the dry season fields are burned. Sowing is mostly carried out without any soil cultivation. Rice is grown in pure stands or mixed with e.g. maize. After 2–3 years, the field is used to grow cash crops such as cacao or coffee, or left fallow. Farmers return after 10–20 years, or later, depending on the recovery of the vegetation and the soil. In such fields, cultivars of shortest duration are grown and African rice is only rarely replaced by Asian rice, e.g. in the forest zone of Guinea and western Côte d'Ivoire.

Along the rivers in northern Senegal and in Mali, in the northern part of the interior delta of the Niger south-west of Timbuktu, in a zone stretching from Diré and Goundam to the series of lakes Faguibine, Gouber and Kamango, rice is grown on floodplains after floods have receded. In this cropping system, rice is sown in moist soil and the crop development relies on ground water. Weeds are few. Both *Oryza glaberrima* and *Oryza sativa* are grown and have a duration of 4–5 months.

**Management** Mechanization, fertilizer application and, with a few exceptions, soil preparation are rarely practised in African rice cultivation. The latter is done with a hoe or, as in the Senegambia, with a long-handled spade. In wet rice cultivation neither crop rotation nor fallow is practised, contrary to the practice for rainfed rice. Weeding in non-flooded areas is manual and often late. In some regions, like the Basse Casamance, weed control is combined with land preparation: a first light irrigation favours the germination of weeds, which can subsequently be eradicated. Under conditions of deep flooding, perennial wild rice (*Oryza longistaminata*) is cut below the surface of the water in order to asphyxiate it. Later, when the water recedes, the rhizomes are pulled up and left on the soil to dry, after which they are burnt. Annual wild rice (*Oryza barthii*) is very common in wet rice fields. It can be recognized by its red awns but it is then too late to remove it. It is characterized by very strong shattering, and as it often ripens before the cultivated rice it multiplies and spreads throughout the rice field. It is sometimes harvested with the rice crop. If the seed is not cleaned carefully, the field will be infested with wild rice within a few years.

**Diseases and pests** The most important and widespread diseases are piriculariosis and smut. Viruses such as the rice yellow mosaic virus (RYMV) and soil parasites (nematodes) often cause large losses. There are few control measures, but some cultivars are resistant to such pathogens.

In irrigated or flooded cultivation the main problems are rizophagous fish (*Distichodus*, *Tilapia*), while birds cause serious damage to all rice crops. Sparrows and weaver birds attack rice

in its milk-ripe stage, while ibis, woodcocks and ducks feed on ripening grain. Children armed with pebbles and slings offer some protection. In upland rice, rodent damage can be prevented by building wooden protection barriers around fields. Buffaloes, elephants and hippopotamus can all cause serious damage. African gall midge (*Orseolia oryziphora*), crickets and grasshoppers are also important pests, as are stem-borers which destroy the apex of the plants and so prevent the formation of inflorescences.

**Harvesting** The harvesting season is October–December. Upland rice is harvested first. Panicles are bundled and stacked in elevated granaries under which a smoking fire is maintained to keep away storage insects. After manual or mechanical threshing, grain can also be stored in bulk in bags. Floating rice is harvested in several rounds mostly from canoes, which leads to considerable losses.

**Yield** Yields obtained under traditional conditions rarely average more than 1 t/ha. In experiments with deep water rice cultivars carried out in Gao and Timbuktu (Mali) from 1984–1987, yields of 1–4 t/ha were obtained.

**Handling after harvest** The produce, whether stored before or after threshing, should be protected against pests, mainly insects and rodents. The paddy should be dried well to reduce the moisture content to a maximum of 14% to achieve good storage and a high milling yield.

**Genetic resources** ORSTOM (now IRD) and CIRAD collected cultivated and related wild forms of rice (both African and introduced) throughout their area of distribution. Between 1974 and 1983, over 3700 samples were collected in Africa and Madagascar, of which 20% are *Oryza glaberrima* and 12% related wild species. These collections are kept in cold storage (4°C, 20% humidity) for medium-term conservation and partly frozen at –20°C for long-term storage at IRD in Montpellier (France). The collection is duplicated at CIRAD in Montpellier and at IRRI in Los Baños (the Philippines).
Currently no *in-situ* conservation programmes of rice of African origin exist but they would be desirable.

**Breeding** While the genetic variability of *Oryza glaberrima* is small in comparison with that of *Oryza sativa*, exciting agronomic characteristics have been found: resistance to RYMV, rice blast (*Pyricularia oryzae*), African rice hispa (*Trichispa sericea*), several stem-borers and nematodes, including *Heterodera sacchari*, *Meloidogyne graminicola* and *Meloidogyne incognita*. African rice shows resistance to salinity, drought and iron toxicity and it competes well with weeds. Few genetic improvement programmes of *Oryza glaberrima* have been undertaken. Hybridization with *Oryza sativa* and the production of early generation back crosses have been successful, but so far cross-breeding has not succeeded in the transfer of favourable characters to *Oryza sativa*. WARDA (West Africa Rice Development Association) is testing fixed material developed from haploid plants to overcome the persistence of sterility in hybrid plants.
Extensive genetic linkage maps have been made for rice, and IRD and WARDA work together in a programme to systematically integrate the genome of *Oryza glaberrima* into that of *Oryza sativa*. The objective is to follow the introgression of small genome fragments of *Oryza glaberrima* into the genetic base of *Oryza sativa* using molecular markers.

**Prospects** For over 30 years it has been predicted that the cultivation of *Oryza glaberrima* would disappear under the pressure of massive introductions of improved cultivars of *Oryza sativa*. And indeed, in the whole of Burkina Faso for example, a strong regression of *Oryza glaberrima* under the pressure of introductions of *Oryza sativa* has been observed, as well as a reduction in the area under irrigated and deep water rice due to lower rainfall. However, African rice has not lost much ground, and this has been explained by the fact that it is highly appreciated by the people of West Africa for its taste and culinary properties, its ability to withstand flooding, and its resistance against several diseases and pests. The genetic variability of African rice is less than that of Asian rice, but is still important. Cross-breeding of *Oryza glaberrima* and *Oryza sativa* should continue to include programmes aiming at the transfer of genome fragments. Such breeding programmes should be carried out in association with a programme of *in-situ* conservation of genetic resources of wild and cultivated rice of African origin. For specific objectives certain regions should be identified, e.g. Guinea for its diversity of rice cultivation systems, the regions of southern Chad/northern Cameroon and the interior delta of the Niger in Mali for the contacts between wild and cultivated forms, and the valley of the Ferlo in Senegal to study spontaneous populations of the annual *Oryza barthii* away from all rice cultivation.

**Major references** 5568, 5569, 5570, 5571, 5572, 5573

**Other references** 5574, 5575, 5576, 5577

**Sources of illustration** 5569 (plant habit, inflorescence), 5578 (spikelet)

**Authors** G. Bezançon & S. Diallo

## OZOROA INSIGNIS Delile

**Protologue** Ann. Sci. Nat., sér. 2, 20: 91, t. 1, f. 3 (1843).

**Family** Anacardiaceae

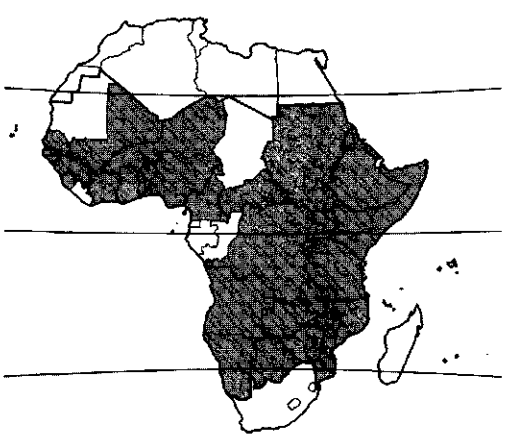
**Chromosome number** $2n$ = unknown

**Synonyms** *Heeria insignis* (Delile) Kuntze (1891), *Heeria reticulata* (Baker f.) Engl. (1906), *Ozoroa reticulata* (Baker f.) R.Fern. & A.Fern. (1965).

**Vernacular names** Tropical resin tree, currant resin tree (En). Mwalika, mzabibu mwitu (Sw).

**Origin and geographic distribution** *Ozoroa insignis* is widespread throughout tropical sub-Saharan Africa, from Senegal east to Eritrea and Yemen, and south to Namibia. It also occurs in South Africa and Swaziland.

**Uses** The wood of *Ozoroa insignis* is used in carving and for poles, but is mainly used as firewood and to make charcoal. The charcoal is of very good quality and can even be used in making gunpowder. The fruits are occasionally eaten and are also ground up and used by Zulu women to scent their hair. In Kenya, a decoction of the root and bark is used to treat kidney and liver complaints, chest pain and diarrhoea, and in Zimbabwe to treat schistosomiasis. In several parts of Africa, roots and bark are used as a vermifuge. In Mali roots are used in the treatment of ulcers and hernias, leaves to treat otitis, colics and dysentery, muscle pains and fever, while decoctions of leafy branches are applied after childbirth and to treat hypertension. The bark is used in Sudan to treat throat infections. In Mali, tooth sticks made of the wood of *Ozoroa insignis* are considered an infallible talisman to attract women.

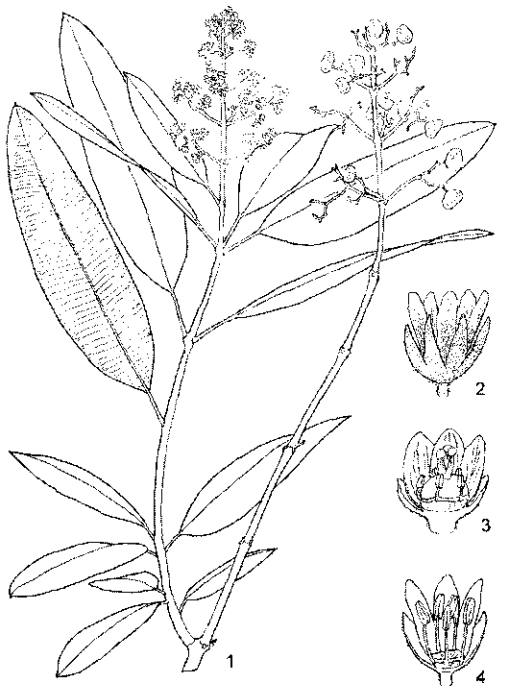


*Ozoroa insignis – wild.*

**Properties** The wood of *Ozoroa insignis* is red in colour and hard, tough and durable, but easy to work. It is resistant to termites. Extracts of the bark and roots have been shown to be lethal to schistosomes which cause urinary schistosomiasis. The results from tests with hamsters infected with *Schistosoma haematobium* cercariae suggested that crude extracts of *Ozoroa insignis* administered orally are lethal to adult schistosomes. Screening of extracts in Zimbabwe revealed that root bark and leaves gave the best results against tapeworms. Air dried twigs collected in Kenya contained a bioactive compound, 6-pentadecylsalicylic acid, toxic to brine shrimp (*Artemia salina*) larvae.

**Description** Dioecious, much-branched shrub or small to medium-sized tree up to 15 m tall, with milky sap; bole cylindrical, sometimes tortuous, up to 50 cm in diameter; bark grey, corky, much fissured, slash reddish; branchlets puberulous to yellowish villous. Leaves alternate or in subverticils of 3, simple; stipules absent; petiole (1–)1.5–3(–5) cm long, subterete, slightly grooved above, densely villous to puberulous; lamina variable in shape, generally oblong to lanceolate or oblong-elliptical, (5.5–)7–22(–27.5) cm × 2–8.5 cm, coriaceous or subcoriaceous, base rounded or cuneate, apex obtuse or acute and mucronate, entire, lateral veins closely parallel, upper surface glabrous or puberulous to villous only on the veins, lower surface usually densely hairy. Inflorescence a terminal or axillary, much-branched panicle, up to 17 cm long; bracts subulate, 3–4(–10) mm long. Flowers unisexual, 5-merous; pedicel 1–1.5 mm long, articulated near apex; sepals ovate to ovate-triangular, 1.5–3.7 mm × 0.7–1.5 mm, acute, dorsally appressed-villous; petals oblong, 2–4 mm × 1–2 mm, whitish to yellowish, apex obtuse, flat, dorsally appressed pilose or villous; male flowers with 5 stamens having subulate filaments and linear-oblong to ovate, dorsifixed anthers, ovary vestigial; female flowers with superior, compressed-globose, unilocular ovary having 3 styles and capitate stigmas, staminodes small. Fruit a transversally ellipsoid, compressed drupe 6–8 mm × 8–11 mm, initially red, turning black and shiny.

**Other botanical information** *Ozoroa* comprises about 40 species, most of which occur in southern Africa. The species are often difficult to




*Ozoroa insignis – 1, female flowering and fruiting branch; 2, female flower; 3, female flower with front sepals and petals removed; 4, male flower with front sepals and petals removed. Redrawn and adapted by M.M. Spitteler.*

distinguish from each other. *Ozoroa insignis* is in section *Ozoroa*, which comprises tree and shrub-like species with petioles longer than 5 mm, rather broad terminal panicles and petals which are flat or concave when fully developed. *Ozoroa insignis* is subdivided into 3 subspecies: subsp. *insignis* with narrow leaves covered beneath with appressed silvery hairs, occurring from West Africa to Ethiopia, Somalia and Yemen; subsp. *latifolia* (Engl.) R.Fern. & A.Fern. with broader leaves covered beneath with appressed hairs, occurring in coastal areas from Senegal to Angola; and subsp. *reticulata* (Oliv.) J.B.Gillett with broader leaves covered beneath with short appressed as well as long spreading hairs, occurring from southern Sudan and Kenya to South Africa. Intermediates between the subspecies and also between *Ozoroa insignis* and *Ozoroa obovata* (Oliv.) R.Fern. & A.Fern. have been recorded from different regions. More taxonomic studies on the delimitation of *Ozoroa insignis* are needed.

**Ecology** *Ozoroa insignis* occurs in wooded grassland and open forest, extending into drier forest and deciduous forest in areas of higher rainfall, often on scarps, denuded soils and rocky slopes. It occurs from sea level to 2200 m altitude.

**Propagation and planting** *Ozoroa insignis* can be propagated by seed or root suckers. The weight of 1000 seeds is about 25 g. Germination is generally good and takes 3 weeks. Seed cannot be stored as it loses viability in a few weeks.

**Harvesting** *Ozoroa insignis* can be coppiced, but information on regrowth is not available.

**Genetic resources** The risk of genetic erosion is considered small given the common occurrence and very wide distribution of *Ozoroa insignis*.

**Prospects** It is likely that the wood of *Ozoroa insignis* will continue to be used for fuel and charcoal production. However, there are no indications that it will become a component of forest plantations for fuel or timber.

**Major references** 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179

**Other references** 2166, 2167, 2168, 2169, 2180, 2181

**Sources of illustration** 2173 (female flower, female flower with front sepals and petals removed, male flower with front sepals and petals removed), 2176 (female flowering and fruiting branch)

**Authors** L.P.A. Oyen

## PANDANUS UTILIS Bory

**Protologue** Voy. îles Afrique 2: 3 (1804).

**Family** Pandanaceae

**Chromosome number** $2n = 60$

**Synonyms** *Vinsonia utilis* (Bory) Gaudich. (1841).

**Vernacular names** Common screw pine (En). Vacoa, baquois, vaquois (Fr). Pandano (Po). Mkadi (Sw).

**Origin and geographic distribution** The origin of *Pandanus utilis* has long been considered to be Madagascar, but more recently it has been suggested that it may have originated in the Mascarene Islands. It has been in cultivation for at least 200 years and is known to be grown in Senegal, Benin, Tanzania, Madagascar, Réunion and Mauritius. It has been introduced to many tropical and subtropical regions, mainly as an ornamental, e.g. in Central America, the Caribbean, the United States (southern Florida, Puerto Rico), Brazil, India and Indonesia. No wild populations are known.

**Uses** The leaves of *Pandanus utilis* are used, mainly in Madagascar, Réunion and Mauritius,

*Pandanus utilis – planted.*

for thatching and for the production of ropes, baskets, mats, hats, place mats and nets. They can also be used to make paper. In Mauritius and Réunion, sugar bags were made from the leaves. The aerial roots have been used for tying and in the production of baskets, mats and hats, and their ends to make coarse brushes for whitewashing.

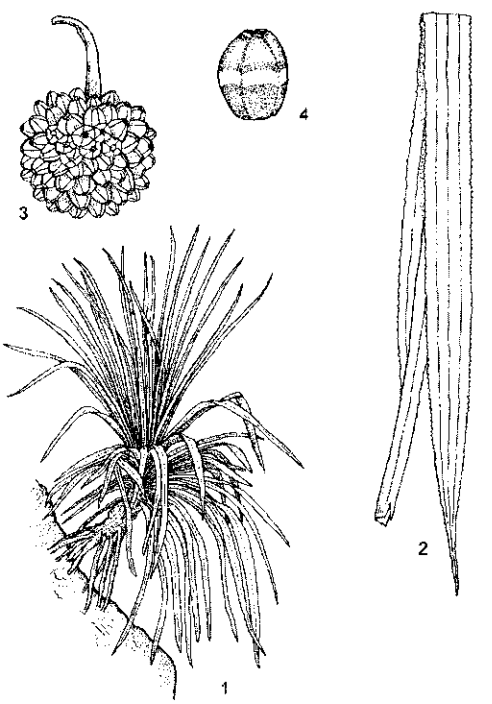
The fruits form a starchy food, palatable after cooking. Cooked male inflorescences are also eaten and are considered to have aphrodisiac properties. Root decoctions are taken against venereal diseases. In Réunion, *Pandanus utilis* trees are used as support for vanilla (*Vanilla planifolia* Andrews). The trees serve as windbreaks mainly along the shore. *Pandanus utilis* is a well-known ornamental in many tropical and subtropical regions. In temperate parts of the United States and Europe young *Pandanus utilis* are grown as indoor foliage plants.

**Production and international trade** No data on production or trade are available. In Mauritius the expanding tourist industry provides considerable demand for local handicraft products based on *Pandanus utilis* and other fibre yielding plants, such as *Furcraea foetida* (L.) Haw. and *Phoenix dactylifera* L.

**Properties** The leaves of young unbranched trees are suitable for the production of bags, mats etc. because they are long and supple, whereas the leaves of older, branched trees are too short and rigid.

**Description** Dioecious small- to medium-sized tree up to 20 m tall, with a smooth, branched trunk and many pale brown basal aerial roots 2.5–7.5 cm in diameter; branches with annular leaf scars. Leaves arranged spirally in 3 series, crowded towards the top of stems, simple, without petiole but with broad clasping base, linear, up to 2 m long, but shorter on old trees, 3–11 cm broad, tapering in a long point at apex, margins and ribs beneath reddish-brown with many sharp, ascending, reddish, 1–4 mm long spines, stiff, erect, with many parallel longitudinal veins. Inflorescence unisexual; male inflorescence a branched spadix 30–80 cm long, in the axil of a pale spathe; female inflorescence a subglobose head of densely crowded ovaries. Flowers unisexual, without perianth; male flowers odorous, with 8–12 stamens inserted pseudo-umbellately on slender columnal excrescences 10–15 mm long; female flowers with 3–8-celled ovary crowned by a sessile stigma. Fruit a dome-shaped, compressed, angular drupe arranged in a pendulous, long-peduncled, subglobose syncarp 15–20 cm in diameter, consisting of up to 200 drupes, each up to 3.5 cm × 4 cm × 2 cm, yellow when ripe, upper half free, base with a purple or red band; pyrene 3–8-celled, containing several seeds. Seeds endospermous, retained within the endocarp.

**Other botanical information** *Pandanus* includes about 600 species and is found from West Africa eastward to Madagascar, the Indian Ocean




*Pandanus utilis – 1, plant habit; 2, leaf; 3, fruiting head; 4, fruit.*
*Redrawn and adapted by W. Wessel-Brand.*

islands, India and most of warmer South-East Asia and Pacific islands. Over 100 *Pandanus* species have been reported from Madagascar, and some 25 species from mainland Africa. *Pandanus utilis* belongs to the section *Vinsonia*.

**Anatomy** Transverse sections of stems of *Pandanaceae* can be distinguished from those of other monocotyledons by the frequent presence of compound vascular bundles, consisting of 2 or 3 conducting strands enclosed by a common bundle sheath. The phloem parts of the separate strands are oriented towards each other, which means that only 1 strand has the normal orientation. As in other species of the section *Vinsonia*, the leaves of *Pandanus utilis* have a spongy tissue with abundant fibres in bundles; these bundles may contain over 150 fibres.

**Growth and development** Seed germination is slow and takes 2–3 months at a soil temperature of at least 27°C.

**Ecology** *Pandanus utilis* is salt tolerant and grows well near the sea. In Réunion it is especially common near the coast.

**Propagation and planting** *Pandanus utilis* can be propagated by seeds, but these are recalcitrant. Pre-soaking of the seeds for 24 hours before sowing is recommended for *Pandanus* in general. The seeds should not be covered with soil. Propagation by stem cuttings and suckers is also possible. In Réunion, planting in April or May at spacings of 1.5–3 m is recommended.

**Management** Pruning and shaping should be done with care, as branches do not have dormant buds. When the terminal growing area is cut off, the branch will not grow further.

**Harvesting** In Réunion, harvesting of leaves starts when plants are 3–4 years old, and may continue for about 20 years.

**Genetic resources** No germplasm collections of *Pandanus utilis* are known. The genetic diversity of the cultivated plants is unknown and deserves more attention in the absence of natural populations.

**Prospects** The importance of *Pandanus utilis* in Africa will remain limited, but its combined use as a fibre plant and windbreak in coastal regions may offer some prospects. The niche market for handicraft products made from *Pandanus utilis* may grow with increasing tourism to countries such as Mauritius.

**Major references** 5511, 5512, 5513, 5514, 5515, 5516, 5517

**Other references** 2016, 3917, 5510, 5518, 5519, 5520, 5521, 5522, 5523, 5524, 5525, 5526, 5527, 5528, 5529, 5530, 5531, 5532, 5533, 5535

**Sources of illustration** 5512 (leaf, fruiting head, fruit), 5534 (plant habit)

**Authors** M. Brink

## PARKIA BIGLOBOSA (Jacq.) R.Br. ex G.Don

**Protologue** Loudon, Hort. brit.: 277 (1830).

**Family** Mimosaceae (Leguminosae - Mimosoideae)

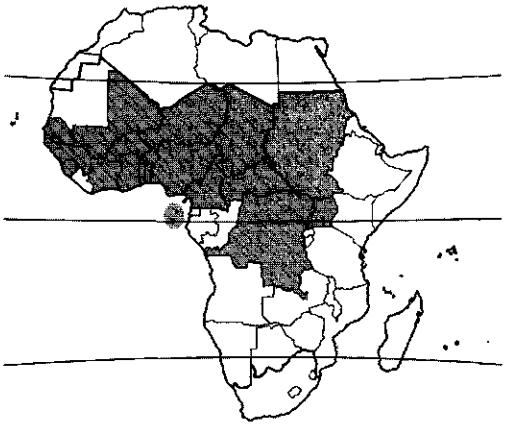
**Chromosome number** $2n = 24, 26$

**Synonyms** *Mimosa biglobosa* Jacq. (1763), *Parkia africana* R.Br. (1826), *Parkia clappertoniana* Keay (1955), *Parkia filicoidea* auct. non Welw. ex Oliv.

**Vernacular names** African locust bean (En). Néré, arbre à farine, caroubier africain (Fr). Farroba (Po).

**Origin and geographic distribution** *Parkia biglobosa* occurs in a belt between 5°N and 15°N, from the Atlantic coast in Senegal to southern Sudan and northern Uganda. The belt is widest in West Africa (maximum 800 km) and narrows to the east. It was probably introduced to São Tomé and Principe. Trial plantations have been established in Tanzania, and African locust bean was introduced to the Caribbean region over 200 years ago, probably as a consequence of the slave trade, and later possibly to Guyana. The use of the fermented beans of African locust bean dates back many centuries and was already described in the 14th Century.

**Uses** African locust bean is a multipurpose tree that is as highly valued as shea butter tree (*Vitellaria paradoxa* C.F.Gaertn.). Fermented seeds ('dawadawa', 'netetu') serve primarily as a condiment for seasoning sauces and soups. Roast-



*Parkia biglobosa – wild and planted.*

ed seeds are used as a coffee substitute known as 'Sudan coffee' or 'café nègre'. Ground seeds are mixed with *Moringa oleifera* Lam. leaves to prepare a sauce, and are also used to make doughnuts. The mealy pulp from the fruits is eaten or is mixed with water to make a sweet and refreshing drink rich in carbohydrates. Boiled pods are used to dye pottery black; the ash is applied as a mordant. The bark is rich in tannins and may be used for tanning hides, but the resulting leather is often of moderate quality especially with regard to colour, which is often reddish, uneven, and darkens when exposed to light.

The leaves are sometimes eaten as a vegetable, usually after boiling and then mixed with other foods such as cereal flour. Young flower buds are added to mixed salads.

In West Africa the bark, roots, leaves, flowers, fruits and seeds are commonly used in traditional medicine to treat a wide diversity of complaints, both internally and externally, sometimes in combination with other medicinal plants. The bark is most important for medicinal uses, followed by the leaves. Medicinal applications include the treatment of parasitic infections, circulatory system disorders, such as arterial hypertension, and disorders of the respiratory system, digestive system and skin. In veterinary medicine, a root decoction is used to treat coccidiosis in poultry. Green pods are crushed and added to rivers to kill fish. The nutritional value of the fish is not adversely affected so long as they are cooked or dried.

The fruit pulp is used as an ingredient of feed for pigs and dogs. The seeds are added to poultry feed after treatment to remove their antinutritional properties. The leaves are a useful, but not very palatable fodder. They should be mixed with other feed because the concentrations of phosphorus, magnesium and sodium are too low. The wood is suitable for making kitchen implements, such as mortars, pestles and bowls, and handles of hoes and hacks, and it is occasionally also used for house building, mainly for indoor construction. It is also used as firewood, and may be suitable for paper production. The fibres of pods (husks) and roots are used as sponges, strings of musical instruments and for the production of small baskets. Burnt pod husks are used in Senegal as an adulterant of, or additive to, tobacco (adding pungency).

African locust bean has a reputation for soil improvement; its leaves are applied as green manure. It is also important in apiculture, being a good source of nectar and suitable for the placement of hives. It may serve as a decorative avenue tree.

African locust bean is very important in West African culture. It plays a role in all major rituals, including those associated with birth, baptism, circumcision, marriage and death.

**Production and international trade** In northern Nigeria the annual production of seeds is estimated at 200,000 t. The products of African locust bean are not important in international commercial trade. However, local trade is important in West Africa, especially in the Sahel region, where the dried or fermented seeds are often transported far from the sites of production, often across country borders.

**Properties** The yellowish fruit pulp is very rich in carbohydrates (ca. 80%), which makes it an excellent energy source. The seeds of African locust bean contain antinutritional factors and have to be processed before use as food or livestock feed. Boiled and fermented seeds contain 35% proteins, 29% lipids, 16% carbohydrates and have good organoleptic properties and a positive effect on intestinal flora. The seeds are good sources of protein, fat and calcium, but contain a non-toxic oil of variable composition. Some sources indicate arachidic acid as the most abundant fatty acid, accompanied by behenic, stearic, palmitic and linoleic acids; other sources mention oleic acid as the most important component (35–50%) with, in addition, equal amounts of behenic, palmitic and stearic acids.

An alcoholic extract of crude seeds showed antihypertensive activity and contractile effect on smooth muscles of the intestine, and increased the tonus and mobility of the uterus. Ichthyotoxic and molluscicidal activities have been recorded for the seeds due to the presence of saponins.

The bark, leaves and pod husks are rich in tannins, which in general have anti-diarrhoeal and antiseptic activities. In tests with mice, analgesic and anti-inflammatory activities have been demonstrated for bark extracts. The aglycone flavonoids in the leaves have spasmolytic activity on smooth muscles, and also vasodilatory and antiseptic effects. Coumarin derivatives in leaf extracts have anticoagulant activity.

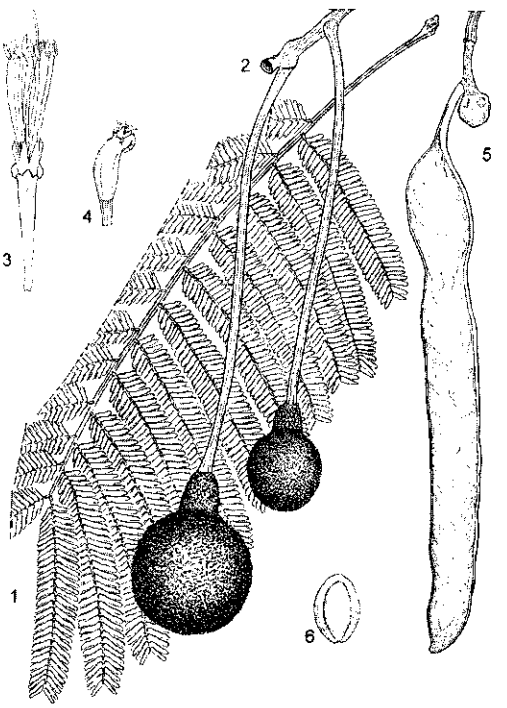
The wood is relatively hard and solid, but not very durable, whitish to yellowish or dull brown. The sapwood is often indistinctly demarcated from the slightly darker heartwood. The density is 550–650 kg/m$^3$ at 15% moisture content.

**Adulterations and substitutes** Fermented seeds of pigeon pea (*Cajanus cajan* (L.) Millsp.), baobab (*Adansonia digitata* L.) and red sorrel

(*Hibiscus sabdariffa* L.) are used as a substitute for fermented *Parkia biglobosa* seeds in Burkina Faso; in Benin, those of *Prosopis* species are used.

**Description** Medium-sized tree up to 20(–30) m tall; taproot often present, lateral roots up to 10(–20) m spreading from bole; bole usually straight and robust, cylindrical, up to 130 cm in diameter, often branching low; bark distinctly longitudinally fissured, often with more or less regular scales between the fissures, thick, ash-grey to greyish-brown, slash fibrous and reddish-brown, exuding an amber gum; crown dense, wide spreading and umbrella-shaped, consisting of heavy branches. Leaves alternate, bipinnately compound, up to 30(–40) cm long; stipules absent; petiole 4–12.5 cm long, swollen at base and there with an orbicular gland; rachis with a caducous awn at apex, bearing up to 17 pairs of pinnae, with a gland between the terminal pinnae; pinnae with 13–60 pairs of leaflets; leaflets sessile, oblong, 8–30 mm × 1.5–8(–10) mm, very unequal at base with a proximal auricle, rounded or obtuse at apex, glabrous but slightly ciliate near apex. Inflorescence a pendulous head arranged racemosely; peduncle 10–35 cm long; capitulum biglobose but distal portion much larger, 3.5–6 cm in diameter, bright red at anthesis, turning salmon-pink, many-flowered. Flowers bisexual, male or sterile, sessile but pseudopedicellate by the fusion of the bases of calyx, corolla and stamens, calyx and corolla tubular, 5-lobed; bisexual flowers in the distal portion of the capitulum, 10–17 mm long, with 10 stamens long exserted and a superior, 1-celled ovary, style filiform, stigma cup-shaped; male flowers in the basal portion of the capitulum, 6–7 mm long, with stamens not exserted, nectariferous; sterile flowers at the extreme base of the basal portion of the capitulum, 6–7 mm long, with rudimentary stamens. Fruit a linear-oblong pod 12–35 cm × 1.5–2.5 cm, slightly falcate, with stipe of 1–4 cm at base, subcylindrical, glabrous and smooth, usually brown when ripe, 5–23-seeded. Seeds embedded in yellowish endocarp, globose-ovoid, slightly compressed, 0.5–1.5 cm long, with distinct pleurogram on lateral face, testa hard, smooth, glossy dark brown.

**Other botanical information** *Parkia* comprises about 30 species and has a pantropical distribution. Only 3 species, all belonging to the section *Parkia*, occur in continental Africa, and a fourth one on Madagascar. The African *Parkia* species seem to be closely related. *Parkia biglobosa* is found in savanna woodland of the Sudanian region, whereas the other 2 continental African species (*Parkia bicolor* A.Chev. and *Parkia filicoidea* Welw. ex Oliv.) are principally rain forest species.




*Parkia biglobosa – 1, leaf; 2, branchlet with inflorescences; 3, bisexual flower; 4, male flower; 5 branchlet with fruit; 6, seed.*
*Redrawn and adapted by M.M. Spitteler.*

**Anatomy** Wood-anatomical description:
– Macroscopic characters:
Heartwood yellowish to pale brown, usually indistinctly demarcated from the whitish to pale yellowish sapwood. Grain straight or slightly interlocked. Texture moderately coarse and uneven. Wood with unpleasant odour when fresh.
– Microscopic characters:
Vessels diffuse, often in pairs, large. Parenchyma abundant, paratracheal aliform and confluent and apotracheal in marginal bands.

**Growth and development** The seedling shows semi-hypogeal germination, the testa splitting but remaining associated with the fleshy, pale green cotyledons. The first leaf is a cataphyll, and subsequent juvenile leaves are bipinnate with usually 3 pairs of pinnae. The whitish to yellowish taproot develops first during germination and gives rise to lateral roots. Growth is comparatively fast: seedlings may reach a height of 1 m in 1 year, and young trees

of superior provenances can reach 7 m in 6-year-old plantations. Tree development is in accordance with Champagnat's architectural model: the trunk is formed by superposition of renewal shoots from lateral buds; the new shoot is initially orthotropic but later becomes plagiotropic; the phyllotaxy is spiral.

Trees start flowering at 5–7 years while still comparatively small. They reach their maximum height after 30–50 years, and can reach an age of 100 years. African locust bean flowers in the dry season in the Sahel region from December to April, slightly earlier in less dry regions. Flowering coincides with loss of leaves; new foliage develops after peak flowering. The flowering period lasts 3–8 weeks depending on the region. Mature fruits develop by April to May. However, 2 periods of flowering and fruiting per year may occur.

Anthesis commences during the afternoon; pollen is shed at dusk and secretion of nectar also reaches a maximum then. Flowers begin to wilt in the night. Bats are the main pollinators, but insects, such as bees and, less often flies and moths, also frequently visit the capitula and pollinate flowers. The flowers are protandrous, which facilitates cross-pollination.

Although humans are probably the main dispersers of seeds today, parrots, hornbills, monkeys, goats, antelopes, squirrels and other rodents also play an important role in seed dispersal.

**Ecology** African locust bean is protected and planted in agricultural fields and wasteland in savanna regions. It tolerates a wide variety of climatological conditions, the principle constant being a dry season of 5–7 months/year. It may grow in regions with an annual rainfall of 500–800 mm in the Sahel, but occurs in regions with much higher rainfall as well, e.g. 2200 mm in Guinea Bissau, and it has even been recorded in regions with over 3500 mm in Sierra Leone and 4500 mm in Guinea. It prefers regions with a mean annual temperature of 26–28°C, but tolerates lower temperatures and occurs up to 1350 m altitude. Although it prefers deep soils with good drainage and fertility, African locust bean can also be found on shallow lateritic soils, stony slopes and rocky hills.

**Propagation and planting** Propagation is mainly by seeds, and these are orthodox. The seeds, with a number of 4500–5000/kg, are still viable after 8.5 years with a germination rate of 78.5% when kept at 4°C and 60% relative humidity. The seeds may be treated with concentrated (97%) sulphuric acid for 10 minutes to break dormancy, and subsequently immersed in water for 24 hours. Germination at an average rate of 95% for freshly collected seeds starts 48 hours after sowing, usually in pots. Small farmers usually soak seeds in water overnight. Seedlings need watering twice a day, and weeding once every 2 weeks. After sowing in seed-beds, young seedlings of 3 days old can be transplanted into pots. Seedlings reach 20–25 cm tall after 20 weeks in the nursery, and are then planted out into the field. Direct sowing is possible, but the success rate depends on soil moisture and the degree of insect and rodent damage, these pests being attracted by the strong smell of germinating seeds.

Preliminary ploughing of the soil contributes to proper establishment of seedlings in the field, with a success rate up to 82% four years after planting. Spacing is usually 10 m × 10 m.

Vegetative propagation of African locust bean is also possible. Grafting, cuttings taken from seedlings, and marcotting of 11–25 years old trees showed good results in Burkina Faso and Nigeria. Experimental *in-vitro* propagation by meristems of young seedlings has given a success rate of 72% in the United Kingdom.

**Management** Thinning of older trees is practised in Burkina Faso, Benin, Mali and Nigeria to promote fruit production and reduce the effect of shade on associated agricultural crops. In Burkina Faso, a decline in millet and sorghum yields occurred when cultivated under African locust bean trees. In some regions of Burkina Faso, regular weeding, and establishment of fire breaks, are customary in plantations of African locust bean.

**Diseases and pests** Fungal infections of leaves by *Cercospora* sp. have been recorded in Guinea, and by *Hypoxylon rubiginosum* and *Phyllachora leonensis* in Sierra Leone. Attacks by a basidiomycete of the genus *Phellinus* may cause desiccation of trees. Infection by loranthaceous hemiparasites of the genera *Tapinanthus* and *Agelanthus* is widespread and may eventually result in the death of heavily infected trees.

**Harvesting** Fruits are normally collected in April and May. Harvesting is either done from the ground using long-staked cutters, or by climbing the trees. When seeds are collected for the production of young plants, 25–30 individual trees of superior stature, good health and at least 100 m apart are selected.

**Yield** The annual production of fruits varies between 25–130 kg/tree, depending on year and site. Average annual production of seeds is 900

kg/ha, of pulp 2.2 t/ha and of husks 1.9 t/ha. The production of trees planted in agricultural fields is on average higher than that of trees growing in wasteland.

**Handling after harvest** The fruits collected for plant production are transported in jute sacks. The fruit valves are opened by removing the fibrous strand extending from the base to the apex, and the seeds with adherent pulp are removed. These are pounded and sieved through a coarse mesh, and subsequently washed to remove the pulp completely. Floating elements are eliminated. The seeds are then dried and impurities removed. The methods for processing seeds intended to be used as a condiment differ between ethnic groups. Normally, dry seeds without pulp are boiled for 24 hours, subsequently cleaned, and boiled a second time for 0.5–2 hours. The seeds are then fermented for 2–4 days in a container covered by leaves or plastic. Fermentation is usually a spontaneous bacterial fermentation under alkaline conditions. In western Nigeria it is often mainly anaerobic, in south-eastern Nigeria partially aerobic. The main bacteria involved are species of *Bacillus*, but others include species of *Lactobacillus*, *Micrococcus* and *Staphylococcus*. The final product is obtained after sun drying for one day. During drying, salt or ash can be added to improve the flavour.

**Genetic resources** Seed collecting missions were organized by the Centre National de Semences Forestières (CNSF), Burkina Faso, in 1990 and 1995 in 12 countries (Senegal, Guinea, Côte d'Ivoire, Mali, Burkina Faso, Ghana, Togo, Benin, Niger, Nigeria, Cameroon and Chad). This resulted in the establishment of a seedbank in Burkina Faso, and in a study of the morphological and genetic variability of *Parkia biglobosa*, which showed that the species has a comparatively high genetic diversity and an important intraspecific morphological variability, mainly present within populations. This enables the conservation of maximum phenotypic diversity by sampling a large number of specimens in a few populations of different parts of the area of distribution.

**Prospects** African locust bean is one of the comparatively few tropical plant species which has been subject to thorough studies concerning its biology and utilization. It has considerable socio-economic importance, and therefore its weakly organized local management deserves more attention, as well as initiatives to improve its products. It is, for example, desirable that appropriate technology be developed for industrial processing of the seeds and pulp. An evaluation of the genetic constitution and production capacity of *Parkia biglobosa* populations within the entire area of distribution is needed as a basis for developing sustainable management systems while meeting the demand for the products.

**Major references** 2107, 5444, 5579, 5580, 5581, 5582, 5583, 5584, 5585, 5586

**Other references** 5587, 5588, 5589, 5590, 5591, 5592, 5593, 5594, 5595, 5596, 5597, 5598, 5599, 5600, 5601, 5602, 5603, 5604, 5605, 5606

**Sources of illustration** 5607

**Authors** S. Sina & S.A. Traoré

## PELARGONIUM ROSAT GROUP

**Protologue** Cultivar-group name proposed in PROSEA 19: Essential-oil plants (1999).

**Family** Geraniaceae

**Chromosome number** $2n = 77$ (heptaploid)

**Synonyms** *Pelargonium asperum* auct. non Ehrh. ex Willd., *Pelargonium graveolens* auct. non L'Hér., *Pelargonium roseum* auct. non Ehrh.

**Vernacular names** Rose-scented pelargonium, Bourbon geranium (En). Géranium rosat (Fr).

**Origin and geographic distribution** *Pelargonium* comprises about 260 species, most originating from coastal South Africa from Namaqualand to Port Elizabeth. Many *Pelargonium* species are so easy to grow and have become so popular as garden plants that they are now cultivated worldwide.

Nearly all cultivars of *Pelargonium* grown for their rose-scented essential oil, called geranium oil, arose in Europe from crossings between introductions from South Africa and are therefore

*Pelargonium Rosat Group – planted.*

of hybrid origin. Commercial cultivation began in the early 19th Century in Grasse, France. Grasse remained the main centre of production until the Second World War. As a result of a change in the economic climate, cultivation there has ceased. The production of *Pelargonium* Rosat Group became important in Algeria, Morocco and Réunion, using plants from Grasse, but after increasing steadily for some time, production declined. The most important producers of geranium oil are currently China, Egypt, Morocco and Réunion, but extensive industries of local importance exist in India and the Crimea Peninsula, the Caucasus and Tajikistan.

In Kenya independent introductions of *Pelargonium* from South Africa (or possibly via India) led to the development of the 'Mawah oil' industry in the early 20th Century. The industry all but ceased during the Second World War. After the war a new industry was built up using plant material from Réunion. The odour of the oil produced was intermediate between the original Mawah oil and Réunion geranium oil. Production of this oil virtually stopped after Kenya gained independence in 1963.

**Uses** *Pelargonium* Rosat Group is grown for the essential oil obtained from the leafy parts. This rose-scented oil is one of the most widely used fragrance materials and an essential component of most rose-scented perfumes and soaps. Extracts of the leaves of *Pelargonium* Rosat Group have antifeedant properties against slugs. In India, the essential oil has shown nematicidal activity against *Meloidogyne incognita*. In Singapore, Malay women sometimes hide a fragrant *Pelargonium* leaf in their hair.

**Production and international trade** The main producer of geranium oil in the past was Réunion and its oil still sets the standard against which oils from other origins are valued. China is now the main producer. Other major producers are Egypt, Morocco, Réunion, India and the former Soviet Union. Annual world production is about 300 t, while demand is estimated at 500 t. The main importers are the United States, Europe and Japan. The production from India and the former Soviet Union is used entirely locally. *Pelargonium* Rosat Group is commonly grown by smallholders. It is often intercropped, e.g. in fruit orchards or with pulses. Investments for mechanization and distillation become profitable for plantations of 200–300 ha.

**Properties** Geranium oil freshly steam-distilled from the herbage of *Pelargonium* Rosat Group is a pale green, mobile liquid with an unpleasant top note partly due to the presence of dimethyl-sulphide. This note disappears on proper aeration or ageing of the oil. When the oil ages, the green colour fades, the oil becomes more yellow and its odour acquires a green leafy-rosy body with minty notes and a sweet-rosy herbaceous dry-out lasting about 5 days. The fragrance compounds are stable under slightly alkaline conditions, e.g. in soap. Geranium oil is only occasionally used as a flavouring material because of its bitter taste.

The main chemical components of geranium oil from Réunion are: geraniol, citronellol, isomenthone, geranyl formate, citronellyl formate, linalool, guaia-6,9-diene and cis-rose-oxide. Although the proportions of the compounds may vary and oils from different origins can be distinguished by their odour, geranium oils are quite uniform in composition.

'Rhodinol ex Geranium' and 'Terpeneless Geranium oil' are selected fractions of vacuum-distilled geranium oil. In this distillation process the monoterpenes and several other low-boiling components are removed as are usually also the 'tail' fractions of the distillation. The odour of terpeneless geranium oil varies according to the supplier. Rhodinol ex Geranium has a delightfully sweet, fresh, rosy, uniform and tenacious aroma, and is used extensively in perfumery.

In Morocco, herbage of *Pelargonium* Rosat Group is often extracted with petroleum-ether to yield geranium concrete, which can be subsequently distilled to produce geranium absolute. The concrete is a dark-green or brownish-green waxy substance with an intensely earthy-herbaceous, somewhat sharp rosy odour with a note of green foliage and is of great tenacity. It is used in expensive soap perfumes. The absolute is a green or dark green liquid with an intense and very powerful odour. The leafy-green top notes are quite pronounced, but the body and dry-out are characterized by rich rosy notes with a minty undertone. The odour is less sharp and more tenacious than that of the steam-distilled oil. The absolute is used in high-class rose bases that are used in a wide variety of perfumes.

Geranium oil has been approved for food use by the Food and Drug Administration (FDA) of the United States under paragraph 182.20. The oil has been 'generally recognized as safe' in the United States (GRAS No 2508) and is registered by the Council of Europe under number 324n. Geranium oil is used in food products, including alcoholic and non-alcoholic beverages. Concentrations are below 0.001% (10 ppm) in finished

products.

**Adulterations and substitutes** Geranium oil is sometimes adulterated with synthetic citronellol and geraniol.

**Description** More or less erect, much-branched shrub, up to 1.4 m tall and 1 m in crown diameter, strongly rose-scented, with an extensive, spreading, superficial root system seldom penetrating below 30 cm; stem soft, grey-green, hairy, becoming darker and woody with age. Leaves opposite or alternate, soft, fragrant, hirsute with glandular and non-glandular hairs; stipules asymmetrically triangular, about 6 mm × 4 mm; petiole up to 3 cm long; blade ovate in outline, about 7 cm × 5 cm, 5–7-palmatifid to palmatisect, base cordate, apex obtuse, margins somewhat revolute. Inflorescence terminal, head-like, with 5–10 flowers in a small compact pseudo-umbel; peduncle up to 6 cm long. Flowers zygomorphic, 5-merous, rose-violet; receptacle forming a hypanthium with a nectariferous spur opening at base of the posterior sepal, lower end of spur thickened and with a nectariferous gland; sepals lanceolate, imbricate, unequal, connate at base, green-brown; petals free, spatulate, 2 posterior larger than the 3 anterior ones; stamens 10, connate at base, staminodial; ovary superior, 5-lobed, style filiform, stigma with 5 recurved, thin branches. Fruit not formed.

**Other botanical information** Most *Pelargonium* species occur in South Africa, several are known from eastern Africa, 2 from Turkey and Iraq, and several occur in south-eastern Australia and Tasmania, some of which may have been introduced from South Africa or developed from such introductions, but most of which were hypothesized to reflect a single late-Pliocene dispersal event, based on DNA sequence.

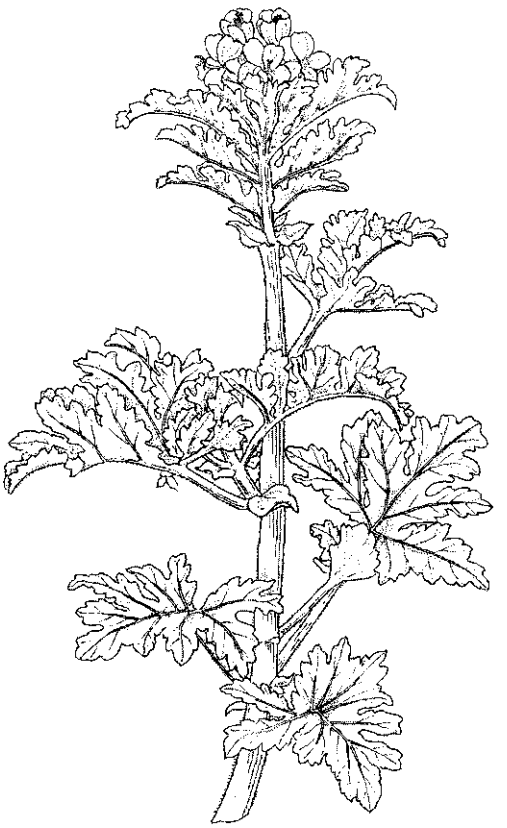
Pelargoniums are commonly called geraniums in commerce and by users. However, botanically, the genus *Geranium* is different from the genus *Pelargonium*. *Geranium* species (about 400) have regular flowers with 10 fertile stamens and without a nectar spur; *Pelargonium* species (about 260) have irregular flowers with usually only 2–7 fertile stamens and a nectar spur adnate to the pedicel.

Many *Pelargonium* species contain essential oil but none of the wild species are directly involved in commercial oil production. Three wild species are indirectly involved in the development of commercial essential-oil cultivars, mainly by hybridization and subsequent vegetative propagation:

– *Pelargonium capitatum* (L.) L'Hér.: $2n = 66$ (hexaploid). Decumbent, much-branched, rose-scented subshrub up to 1 m tall, with crisped, villous, 3–5-lobed or -partite leaf blades, flowers pale pink to pink-purple in a 8–20-flowered head-like pseudo-umbel and with pedicel much shorter than the hypanthium. It grows wild along most of the south coast of South Africa on sandy dunes or flats.

– *Pelargonium graveolens* L'Hér.: $2n = 88$ (octoploid). Synonym: *Pelargonium asperum* Ehrh. ex Willd. Erect, much-branched, strongly rose-scented shrub, up to 1.3 m tall, with palmatipartite to pinnatisect leaf blades soft to the touch (villous) and with irregularly pinnatipartite to pinnatisect segments, flowers white to pinkish-purple in a 3–7-flowered pseudo-umbel, pedicel usually shorter than hypanthium. It grows wild in mountainous areas in southern Africa, and is recorded from Zimbabwe, Mozambique and South Africa (northern Transvaal and south-eastern Cape Province).

– *Pelargonium radens* H.E.Moore: $2n = 88$ (octo-



*Pelargonium Rosat Group – flowering branch. Source: PROSEA.*

ploid). Synonym: *Pelargonium radula* (Cav.) L'Hér. An erect, much-branched, rose-scented shrub, up to 1.5 m tall, with palmatisect to pinnatisect leaf blades with narrow, pinnatisect, scabrous segments, flowers pinkish-purple in a 3–8-flowered pseudo-umbel and pedicel as long as hypanthium. It grows wild in coastal regions of the southern Cape Province of South Africa, often in mountainous, rather moist habitats.

*Pelargonium* Rosat Group consists of those cultivars yielding commercial rose-scented geranium oil. This group originates from the cultivars that have long been grown in Grasse (France) and which have been distributed from there to all major production areas. It is not clear, however, to what extent later independent introductions have contributed to the complex of hybrids. The typical and commercially most important cultivar in Réunion is 'Rosé', a hybrid between *Pelargonium capitatum* and *Pelargonium radens*. Other cultivars may be hybrids of *Pelargonium capitatum* and *Pelargonium graveolens*. Most of these cultivars have 77 chromosomes, and their morphology and essential oil yield are also in between their natural parents. However, the oil composition depends on the *Pelargonium capitatum* parent, which transmits the ability to synthesize geraniol and citronellol rather than isomenthone. Furthermore, the presence of guaia-6,9-diene is also inherited from *Pelargonium capitatum*. Réunion type cultivars are typical of *Pelargonium* Rosat Group. Future research should more clearly demarcate the cultivar-group.

Before the Réunion Rosat Group cultivars were proven to be hybrids of *Pelargonium capitatum* and *Pelargonium radens*, the pelargoniums grown for their essential oil were often called *Pelargonium graveolens*, *Pelargonium roseum* or *Pelargonium asperum* in the botanical literature, with scant regard for botanical accuracy. The name *Pelargonium roseum* has been applied by various authors to 3 different hybrid combinations (one of which possibly includes Rosat Group cultivars but is not the oldest one and should be rejected). *Pelargonium* ×*asperum* was proposed by H.E.-Moore as the correct name for the hybrid of *Pelargonium graveolens* and *Pelargonium radens*. As *Pelargonium graveolens* is not involved in the origin of typical Rosat Group cultivars, *Pelargonium graveolens* and *Pelargonium* ×*asperum* are not acceptable as correct names. Moreover, a cultivar classification is more appropriate for cultivated plants; hence *Pelargonium* Rosat Group is preferred.

'Scented-leaved pelargoniums' are a different group of cultivars grown as ornamentals. This group contains cultivars with a wide range of habits and foliage, often with numerous small flowers and characterized by their fragrance. Their scent varies and may be apple, peach, orange, lemon, nutmeg, peppermint, balsam or rose. 'Attar of Roses' and 'Clorinda' (rose-scented), 'Chocolate Peppermint' and 'Joy Lucille' (peppermint-scented), 'Mabel Grey' and 'Lady Mary' (lemon-scented), 'Peach Cream' (peach-scented), 'Prince of Orange' (orange-scented) and 'Viscosissimum' (balsam-scented) are some well known cultivars. Their relation to wild species with fragrant leaves should be further investigated, e.g. the relation to *Pelargonium crispum* (Bergius) L'Hér. (lemon-scented), *Pelargonium fragrans* Willd. (nutmeg-scented), *Pelargonium odoratissimum* (L.) L'Hér. (apple-scented) and *Pelargonium tomentosum* Jacq. (peppermint-scented).

Although the essential oils extracted from *Pelargonium* are called geranium oil in commerce, only one true *Geranium* species is grown commercially for its essential oil: *Geranium macrorrhizum* L., yielding zdravetz oil. All zdravetz oil is produced in managed natural stands in Bulgaria, the former Yugoslavia and former Soviet Union.

**Growth and development** Oil content of *Pelargonium* Rosat Group changes during development. In Israel, it was found to be 1.2 g per 100 g dry matter at the beginning of flowering, gradually increasing to 1.3% at full bloom and dropping to 1.2% one week later and to 0.6% at the end of blooming. At full bloom, oil content was found to be highest in the flowers (3.3%), followed by the leaves (1.8%). Stems contained only traces of oil.

Main flowering periods in Réunion are April–May and August–September.

**Ecology** For optimum growth *Pelargonium* Rosat Group requires an average annual rainfall of 1000–1500 mm. Rainfall may be evenly distributed, but a 3-month dry period improves herbage yield and oil content. Oil produced after a 3-month wet period, however, had a slightly milder note and an increased geraniol content. Heavy rainfall combined with mist or fog may lead to root and stem rot. The plants require much light; cloudy weather reduces leaf growth and oil content. An average daytime temperature of 20–25°C is optimal, but growth is acceptable from 15–30°C and absolute maximum temperatures of 42°C for several weeks are tolerated in Hyderabad, India. Growth stops at 6°C; frost and even prolonged exposure to 3°C kills the plants. In temperate areas, it is therefore grown as an

annual crop. In Réunion *Pelargonium* Rosat Group can be grown up to 1400 m altitude, but from sea-level to 400 m altitude other crops are more profitable. In the highlands of Kenya it is grown at 2000–2500 m altitude, in southern India at 1200–1500 m. Altitude and temperature have a pronounced influence on the character of the oil. In a trial in India herbage and oil yields at 900 m altitude were higher than at 550 m and at 2200 m. At the lower altitudes the essential oil was richer in isomenthone and citronellyl formate, at higher altitudes in menthone, citronellol and geraniol. At the lowest altitude the content of rose oxides was significantly higher than at the other altitudes. High maximum temperatures reduce oil content, but increase the content of citronellol and citronellyl formate. In Réunion cyclones often cause havoc in *Pelargonium* fields; soils saturated by prolonged heavy rains associated with cyclones also cause extensive damage.

*Pelargonium* Rosat Group grows best on fertile, well-drained, slightly sandy soils with pH 5.5–8.0. Heavy clays, alkaline and very acid soils are generally unsuitable. Waterlogging is not tolerated. Selected cultivars can tolerate low to moderate salinity.

**Propagation and planting** *Pelargonium* Rosat Group is propagated vegetatively, mostly by stem cuttings. Micropropagation methods have given excellent results, but are more expensive. Leafy stem cuttings of 15–20 cm length with 4–6 nodes and a terminal bud are taken from healthy plants. Some 20–25 cuttings can be taken from a vigorous plant. Direct planting is common and striking rates are high when planted in moist soil, but nursery planting is also used. Before the cuttings are planted the lower leaves are removed and the base of the stem is cut at an angle and dipped in a fungicide. Cuttings should be planted immediately after preparation. 30,000–50,000 cuttings are needed to plant 1 ha. Equipment for mechanized planting is available, but manual planting is common. Prior to planting careful soil cultivation and removal of weeds and crop residues are essential, as *Pelargonium* Rosat Group is very susceptible to root infections and weeds are difficult to remove from an established crop.

**Management** Regular weeding of *Pelargonium* Rosat Group is needed until the crop is established. Care is needed to avoid damage to the shallow root system. Herbicides have been used successfully and should be applied as directed sprays with drift shields. For small farmers, who do most weeding manually, spot spraying against persistent weeds is recommended.

Nutrient uptake is high, but amounts reported vary greatly. In Réunion a crop of 7 t/ha fresh herbage removes an estimated 100 kg N, 14 kg P, 134 kg K, 179 kg Ca, 15 kg Mg and 10 kg S; in India the estimated amount of nutrients removed by a similar crop was 110 kg N, 25 kg P, 40 kg K, 45 kg Ca and 30 kg Mg. Fertilizers have little effect on the oil content of the foliage. Where irrigation facilities are available for other crops in a rotation, supplemental irrigation is recommended during dry periods and to promote regrowth after harvesting. The economic life of a well-managed plantation can be 10 years. It should not be less than 5–7 years as the cost of establishment is high. After this period rotation with other crops is recommended.

**Diseases and pests** In *Pelargonium* Rosat Group diseases generally cause more damage than pests. The most damaging are leaf diseases such as anthracnose (caused by *Glomerella*, *Gloeosporium* and *Colletotrichum* spp.), leaf spot (caused by *Alternaria*, *Cercospora*, *Fusarium* spp.), and rust (caused by *Puccinia pelargonii-zonalis*). *Pelargonium vitifolium* (L.) L'Hér. has good resistance to anthracnose and has been used in breeding programmes in Réunion. Root and stem rots may cause severe damage in newly planted fields, but can be controlled by dipping cuttings in a fungicide solution before planting. Established plants may become infected when soil moisture is high or during periods of high air humidity. Frequently recorded causal agents include *Xanthomonas pelargonii* causing black rot, *Pythium* spp. causing root rot and *Sclerotinia* spp. causing stem or root decay. Spraying a fungicide along the plant row after harvesting can often contain an outbreak. Resistance to some diseases has been found in Indian selections and in ornamental cultivars. Several pathogenic viruses have been isolated from *Pelargonium*, thus only virus-free cuttings should be used for propagation. Nematodes have been recorded, but seem to cause only limited damage, possibly because geranium oil has nematicidal properties. *Pelargonium* plants grown for essential oil are much less affected by insects than ornamental cultivars. A large number of insects including aphids, caterpillars, myrids, scale insects and whiteflies have been recorded, but rarely justify spraying with insecticides, especially as the residues of many insecticides adversely affect the quality of the oil.

**Harvesting** Under favourable conditions the first harvest of *Pelargonium* Rosat Group can be made when the crop is 6–8 months old. Cutting

too early may kill plants or retard regrowth. Subsequently, harvesting is done 2–3 times per year. To obtain maximum oil yield the crop should be sampled regularly to determine its oil content, but cutting time is normally related to plant height and flowering. Cutting is done manually or mechanically, normally at 12–20 cm above the ground. Field trials should establish the optimum cutting height, as nearly all oil is contained in the top 15 cm of a plant. Harvesting is best done during slightly overcast, but dry weather. Heavy rain or several misty days can reduce oil content to half; cutting should then be suspended until oil content has recovered. Cut branches should be loaded directly into a cart. Any contamination with soil, especially if rich in iron or aluminium, can affect oil quality.

**Yield** Annual herbage yields of *Pelargonium* Rosat Group in Réunion are 15–30 t/ha, the average being 18 t/ha, yielding 5–20 kg oil. In India yields average 6–10 t/ha and may reach 20 t/ha.

**Handling after harvest** Wilting of the herbage of *Pelargonium* Rosat Group before distillation may increase still efficiency, but should be carefully managed to avoid contamination with soil and loss of oil due to intense insolation. Geranium oil is obtained by water or steam distillation, the distillation method having little influence on oil quality. In Réunion the oil is produced by peasants operating small simple stills. The desired quality of the oil is maintained by traders who mix numerous small lots of oil. Modern steam-distillation equipment is loaded directly or after chopping the herbage. The load should not be too densely packed as this will channel the steam and cause local overheating. Since significant quantities of aroma compounds remain in the distillation water, cohobation is used. Up to 25% of the oil yield may be obtained from solvent extraction of the distillation water. This 'secondary oil' has a higher free alcohol content, but contains less ester. Water remaining in direct-fired water stills contains a different oil. This oil should be discarded as it contains undesirable compounds, probably as a result of overheating. Crude oil should be dried, filtered and stored in opaque containers, preferably at a temperature below 10°C. At higher temperatures the ester content decreases and the content of acids increases.

Solvent extraction of herbage yields a concrete that for most purposes should be distilled with alcohol to remove wax.

**Genetic resources** Germplasm collections of *Pelargonium* Rosat Group have been established at the Horticultural Research Station, Kodaikanal, India and at the Indian Institute of Horticultural Research, Bangalore, India. Morphological and yield (herbage and oil) studies have been made to identify promising strains.

**Breeding** Breeding work in *Pelargonium* Rosat Group is hampered by male sterility in most cultivars. Most breeding work has therefore relied on selection of superior plants. Cultivars with a high yield potential and high oil content have been selected in India, e.g. PG-7, PG-20, Alg-4n. Tolerance of heavy rainfall conditions and associated tip rot has also been found in some cultivars. Cultivars with high geraniol content and a moderate resistance to wilt have been identified in Egypt. In India a mutant characterized by fertile stamens and gigas traits has been found in a cultivar originally from Réunion. Hybrids between this mutant and a seed-setting cultivar (Alg-4n) form the basis of a breeding programme.

**Prospects** Because of the strong demand for geranium oil, *Pelargonium* Rosat Group will remain an important crop. Its adaptability to tropical conditions, and the relative uniformity of geranium oil from different origins seems to justify testing this crop in parts of the tropics where it is not yet cultivated and the basic ecological requirements prevail. More research is needed to demarcate the cultivar-group more clearly and to clarify its origin and affinity, which is essential for developing successful breeding programmes.

**Major references** 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196

**Other references** 2182, 2183, 2184, 2185, 2186, 2187, 2197

**Sources of illustration** 2182

**Authors** U.A. Dasuki

## RAPHIA HOOKERI G.Mann & H.Wendl.

**Protologue** Trans. Linn. Soc. 24: 438 (1864).

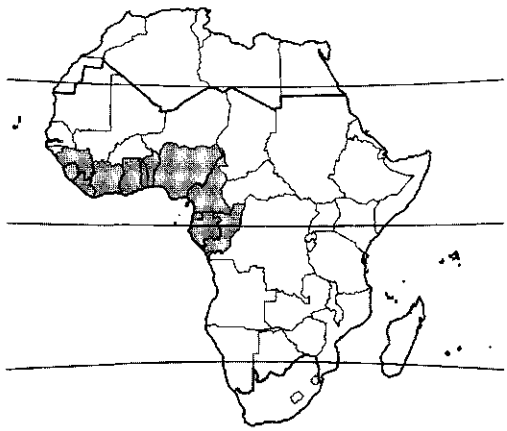
**Family** Arecaceae (Palmae)

**Chromosome number** $2n = 28$

**Synonyms** *Raphia gigantea* A.Chev. (1932), *Raphia sassandrensis* A.Chev. (1932).

**Vernacular names** Raphia palm, wine palm, Ivory Coast raphia palm (En). Raphia (Fr). Ráfia (Po). Mwale (Sw).

**Origin and geographic distribution** *Raphia hookeri* is found from Gambia through the Guinea forest zone of West Africa to Cameroon, Gabon



*Raphia hookeri – wild.*

and Congo and possibly to Angola. It is occasionally cultivated, e.g. in Nigeria. Outside Africa it is grown in India, Peninsular Malaysia and Singapore.

**Uses** *Raphia hookeri* yields two valuable types of fibre: piassava or bass, and raffia. The very strong piassava fibre is obtained from the petiole and leaf sheath and is used locally to make weather-resistant coarse ropes, belts for climbing oil-palms and brushes. It is exported for the production of hard brooms and brushes. Piassava fibre is used to make exceptionally strong paper. It can also be used to produce very fine-textured charcoal, much favoured for the manufacture of home-made gunpowder. The soft but strong raffia fibre has also been considered a potential source of pulp for paper production. It is obtained by pulling off ribbon-like strips from the upper surface of the leaflets of young unfolding leaves and is used to make mats, hats, baskets, bags, ropes, hammocks, ceremonial costumes, etc. It may be woven into cloth. In Europe it is used as tying material for horticulture and handicrafts. The leaves of *Raphia hookeri*, often split lengthwise, are used for thatching, though they last only 1 year. They are also used to make mats, baskets and other articles of wickerwork, and are used for hut-walls and fences. The midribs and petioles of the leaves ('raffia bamboo' or 'bamboo') are used for poles, rafters, ladders, furniture and cross-bearers in canoes. Split lengthwise they are used to make screens.

Sap tapped from the stem when the tree nears the flowering stage ferments rapidly into palm wine ('mimbo'), a very popular drink throughout West Africa. In Nigeria it is bottled for commercial purposes, although there is a risk that bottles can explode due to continuing fermentation. The wine is distilled into a strong alcoholic liquor and can also be used as bakers' yeast. The young terminal bud or 'palm cabbage' is eaten as a vegetable.

The raw fruit is poisonous and is crushed for use as fish poison. Boiled fruits are eaten in Nigeria. The oily mesocarp is used in traditional medicine for its laxative and stomachic properties and as a liniment for pains. Boiled or roasted kernels are sometimes eaten. Larvae of the rhinoceros beetle (*Oryctes* sp.), found in rotting stems, are collected and eaten.

**Production and international trade** *Raphia hookeri* is the main piassava yielding *Raphia* species. Its piassava has been exported to temperate countries (mainly Europe) for the production of brooms and brushes since the end of the 19th Century, when the supply of South American piassava (from *Attalea funifera* Mart. and *Leopoldinia piassaba* Wallace), used in Europe for brooms since the middle of the 19th Century, could no longer meet demand. The trade reached its peak in the 1950s and 1960s (7000 t exported from Sierra Leone, the main exporting country, in 1964; 5300 t from Nigeria in 1966; there was also trade from Guinea), after which it declined with the advent of plastic brooms. The particular qualities of African piassava for broom-making are such that it still enters the international market. The main types of African piassava fibre in trade are 'Sherbro', 'Sulima' and 'Calabar' ('Opobo'). Sherbro and Sulima are obtained from the petiole, the former from *Raphia hookeri* and the latter from *Raphia palma-pinus* (Gaertn.) Hutch., often with an admixture of *Raphia hookeri* fibres, whereas Calabar is extracted from the leaf sheath of *Raphia hookeri*. The leaf sheaths of *Raphia palma-pinus* are rather short and do not yield high quality fibre. Most of the raffia of commerce is produced in Madagascar from *Raphia farinifera* (Gaertn.) Hyl.

Although palm wine is the main product of *Raphia hookeri* in several regions, no production data are available. The wine is mainly used and traded locally. Distilled palm wine is also mainly traded locally although there is some trade between neighbouring countries.

**Properties** Piassava fibre is water resistant, hard-wearing, and has the right balance between stiffness and elasticity to give a firm stroke to a broom and sufficient spring action to make the broom self-cleaning. The best piassava fibre is cylindrical with a firm wall and a soft core and a diameter of 1–1.5 mm. It is obtained from the

sides ('wings') of the petiole, whereas fibre from the upper and lower surfaces is of only reasonable quality. Fibres near the central flattened ridge are woody and brittle. The central core of the petiole gives a soft fibre ('straw' or 'piassava tow') which may be used as a substitute for coir from coconut. The best quality Calabar fibre is obtained from the sides of the leaf sheath, i.e. not near the suture and not near the midrib. Fibre obtained from the midrib of the leaf sheath is softer and more pliable making it suitable for plaiting ropes. Calabar piassava is stiffer than Sherbro and Sulima and tends to be black, whereas Sherbro and Sulima are pale at harvest, turning darker during retting. Mature leaves yield higher quality piassava fibre than younger leaves. *Raphia hookeri* yields good quality raffia with high tenacity.

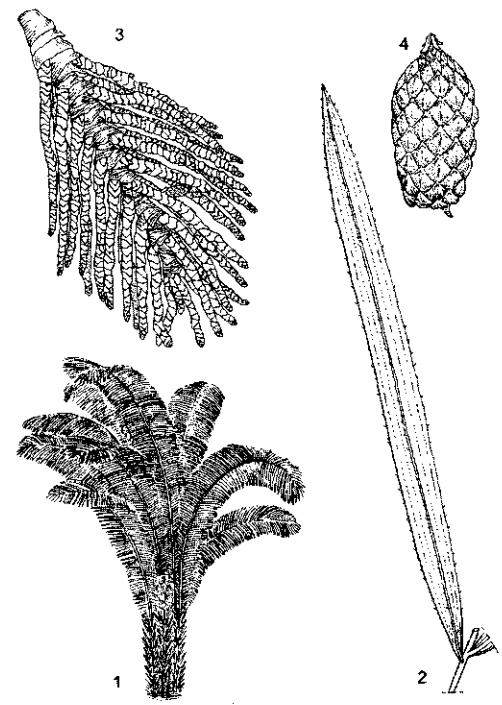
Both the stem and the petiole of *Raphia hookeri* are suitable as raw material for the paper industry. Stem fibres are mostly thick walled and, on average, 2.4 mm long and 30 μm wide. The width is rather variable, ranging from 17–46 μm. The fibres of the petioles are on average 1.7 mm long and 18 μm (10–27 μm) wide. Many fibres have scalloped walls. The pitted vessel elements of the stem are few in number but very large, up to 5 mm long and 350 μm wide, whereas those of the petioles are generally smaller. Pulp from *Raphia hookeri* also contains rounded, thick-walled parenchyma cells and spherical silica bodies. Dry stems consist of about 74% fibre, 25% parenchyma, and 1% vessel elements.

Palm wine obtained from *Raphia hookeri* is attractively milky-white in colour, but is weaker and less sought after than that from oil palm. When fresh, the sap tastes like ginger beer. The alcohol content of the sap increases from less than 2% to about 5% during the first 8 days of tapping, remaining constant thereafter. *Leuconostoc* and *Lactobacillus* bacteria are present in the early stages of fermentation, while the yeast *Saccharomyces cerevisiae* is mainly responsible for the alcohol fermentation.

The major fatty acids in mesocarp oil and seed oil are linoleic acid, palmitic acid and oleic acid. Mesocarp oil from *Raphia hookeri* resembles that from oil palm in colour, taste, odour and chemical composition, except that it contains more linoleic acid, giving it a higher unsaturated acid content. The fruit also contains toxic and antinutritional factors, such as hydrocyanic acid, tannins, oxalate and phytic acid. Cooking reduces the levels of these. The kernel contains per 100 g : moisture 11 g, protein 8 g, fat 1 g, carbohydrates 63 g, fibre 8 g and ash 9 g.

**Adulterations and substitutes** *Raphia* species used for similar purposes as *Raphia hookeri* include *Raphia africana* Otedoh, *Raphia farinifera*, *Raphia mambillensis* Otedoh, *Raphia palma-pinus*, *Raphia regalis* Becc., *Raphia sudanica* A.Chev. and *Raphia vinifera*. The original sources of piassava fibre are *Attalea funifera* ('Bahia piassava' or 'Bahia bass') and *Leopoldinia piassaba* ('Para piassava' or 'Monkey bass'), both from Brazil.

**Description** Monoecious tree, trunk up to 10 m tall and 30 cm in diameter, occasionally with 1–4 suckers; upper part of trunk with blackish fibres (marcescent leaf-bases). Leaves arranged spirally, pinnate, up to 12 m long, erect, dark green and shining above, waxy and glaucous below; sheath 3–4 m long, unarmed, splitting opposite the petiole; petiole 3–4 m long; leaflets 1–1.5 m × 4–5 cm, about 200 on each side of the rachis, terminal segments gradually narrowing to a fine point and having spines on upper side of midrib and on margins. Inflorescence axillary, pendulous, 2.5 m or more long, branched to 2 orders, compressed-cylindrical, with crowded branches; branches bearing many curved ultimate




*Raphia hookeri – 1, plant habit; 2, leaflet; 3, inflorescence; 4, fruit.*
*Redrawn and adapted by W. Wessel-Brand.*

branchlets in 4 rows but mostly compressed into one plane; branchlets 15–23 cm long, rigid; branches and branchlets with short-tubular, truncate bracts at base. Flowers unisexual; male flowers at apex of inflorescence branchlets, female flowers at base, 3-merous; male flowers 1.5–2.5 cm long, with 1 bracteole slightly longer than thick, calyx with blunt lobes, corolla much longer than calyx, curved, with segments thickened near the tip, stamens (15–)18–22(–24), with erect, linear anthers; female flowers larger than male, with 2 bracteoles, calyx as in male, corolla about as long as calyx, with acuminate segments thickened near tip, staminodes 12–15, ovary superior, 3-celled, stigma sessile, recurved, subulate. Fruit a 1-seeded berry, inversely conical or ellipsoid, 6–12 cm × 4–5 cm, with stout beak 1–1.5 cm long, more or less obliquely tipped, covered with scales in (11–)12(–15) vertical rows; scales convex, slightly less broad than long, narrowly furrowed, reddish-brown or pale yellowish-brown with darker point, obtuse at the base, almost entire. Seed 6–7.5 cm × 3–3.5 cm, oblong, irregularly grooved; albumen narrowly ruminate. Seedling with hypogeal germination, with tap root and some adventitious roots; first 3–4 leaves strongly reduced and irregularly incised, subsequent leaf 50–100 cm long and with about 12 leaflets at each side of the rachis.

**Other botanical information** *Raphia* comprises 28 species, mostly African, predominantly found in swampy areas. One species, *Raphia taedigera* (Mart.) Mart., is found in tropical America. Three varieties of *Raphia hookeri* have been distinguished: *Raphia hookeri* var. *hookeri*, *Raphia hookeri* var. *planifolia* Otedoh and *Raphia hookeri* var. *rubrifolia* Otedoh. Locally, different forms of *Raphia hookeri* are recognized.

**Anatomy** The hypodermis of *Raphia hookeri* leaflets consists of thick fibres arranged in a continuous ribbon-like layer with no discontinuities. In *Raphia vinifera* and *Raphia sudanica* the fibres are not arranged in a ribbon-like layer, but are discontinuous, resulting in less tenacity.
In both the stem and petiole the vascular system consists of bundles which are scattered throughout the ground tissue and the cortex is very narrow or non-existent. The peripheral vascular bundles of the central cylinder are congested and have a well-developed fibrous sheath. The vascular bundles are separated by parenchyma. In the inner part of the central cylinder, the vascular bundles are more diffuse than in the periphery. Stem fibres are more numerous than in the petiole, partly because the vascular bundles are closer and partly because the fibrous bundle sheaths are thicker in the central parts.

**Growth and development** *Raphia hookeri* develops in accordance with Tomlinson's growth model. When young the main stem forms a few basal suckers. *Raphia* species have monocarpic stems, i.e. they flower and fruit only once, followed by death. Inflorescences are produced more or less simultaneously in the axils of the most distal leaves. Tapping for wine may damage the developing inflorescence, making flowering impossible and accelerating death. The time from planting to flowering in *Raphia hookeri* is 3–7 years. In Nigeria, *Raphia hookeri* flowers in May. The pericarp reaches maturity at 24–30 months, the seed matures in about 30–33 months. Lipid accumulation in the pericarp mainly occurs between 30–36 months after pollination. Ground squirrels, bats and birds feed on the mesocarp.

**Ecology** *Raphia hookeri* occurs in freshwater swamps and on river banks in the Guinean Zone of West and Central Africa. It generally does not tolerate saline conditions; near the Guinea coast it is replaced by *Raphia palma-pinus*. In some places (e.g. southern Benin and south-eastern Nigeria) human activity (cutting of dicotyledonous trees, planting of *Raphia hookeri*) has turned natural swamp vegetation into 'rafiales', in which *Raphia hookeri* is the dominant species. The soils of Nigerian freshwater swamps are light textured and generally acidic.

**Propagation and planting** Managed stands of *Raphia hookeri* are mostly left to rejuvenate naturally by seed. In Nigeria, selected trees are left untapped for this purpose. Occasionally, *Raphia hookeri* is propagated from seed. The germination period may range from 1–24 months, and the germination rate from 30–60%. Young plants are easily transplanted. In nurseries, a spacing of 30 cm × 30 cm is recommended. It has been claimed that seeds should be sown ventral side upwards, because the embryo is located on this side, but research has shown that seed orientation does not influence germination or seedling growth.
In Nigeria, *Raphia hookeri* sometimes serves as support for yams. In Benin, tomatoes, cassava, sugar cane, red pepper and other crops are sometimes grown on earth ridges in *Raphia hookeri* swamps.

**Management** In West Africa, *Raphia hookeri* is exploited from natural stands, but it is also planted and tended on upland farms. Suckers are often removed by farmers to promote growth of the main stem.

**Diseases and pests** *Raphia hookeri* in Nigeria is affected by seedling blight, caused by *Glomerella cingulata*. Symptoms are transparent yellow circular spots appearing on the youngest fully expanded leaves, later becoming necrotic and coalescing. The infection spreads from the tip to the base of the leaflet and may lead to leaflet shedding. Severely infected seedlings may die. Fruit rot, caused by *Thielaviopsis paradoxa* (synonym: *Chalara paradoxa*), also occurs in Nigeria, causing dark brown rot of the mesocarp. It is a weak pathogen entering fruit via wounds, sometimes killing the embryo, and leading to loss of planting material. The aphid *Cerataphis palmae* may cause considerable damage, e.g. in Nigeria.

**Harvesting** Because palm wine from *Raphia hookeri* is highly prized, cultivators are reluctant to diminish plant vigour by cutting leaves for their fibre. However, dying leaves can be harvested for piassava with little effect on wine yields. Removing the leaf sheaths requires considerable leverage, and is usually a team effort. Stout poles, flattened at the end, are inserted into the suture of the lowest leaf sheath and the stem, and the sheath is levered away, while additional weight is applied to the petiole. As it is easier to remove the leaf sheaths from a fallen trunk, palms are often felled after tapping and before fibre harvesting. In Nigeria, external fibres covering the trunk are sometimes set on fire, after which the tree is felled with an axe, the leaves and lower trunk are cut off with a cutlass, and the leaf stalks are cut and removed from the base to the crown successively.

Tapping for palm wine begins when the first small leaf (2–3 m long) subtending an inflorescence appears. A cavity is cut in the stem just below the growing point and the resulting sap is collected in a calabash. When sap flow diminishes, the hole is enlarged until it is about 50 cm × 20 cm. *Raphia* can usually be tapped for 18–25 days before the tree dies. Unlike oil palm, *Raphia* palms are rarely felled before tapping. For maximum oil yields, the fruits should be harvested 36–42 months after pollination.

**Yield** No data on fibre yield are available. Palm wine yields of 870 l have been recorded from a single tree in a 2-month period from cutting to death, but average yields are about 100 l per palm.

**Handling after harvest** Piassava fibre extraction is different for leaf sheaths and petioles. The tissue of older leaf sheaths is already moribund and has started to soften, and the outer thicker and more brittle fibres can be stripped off or, in some areas, are removed by burning the trunk. Starting from the outer 'wings', the useful fibres are sequentially stripped by hand. When removal of the fibres is difficult, usually in younger leaf sheaths, the tissue is beaten with a stick or the trunk is left exposed to the elements until the tissue has softened. The traditional practice of fibre extraction from the petiole, with its more solid tissue and hard epidermis, is to split the petiole along the longitudinal axis into 3 or 4 splits, which are tied into bundles and immersed in water. The retting period varies from a few weeks to 2–3 months. After retting, the fibres can be stripped off relatively easily. Retting influences the appearance of the fibres. Sherbro and Sulima piassava, somewhat pale coloured at harvest, turn brownish on retting. Material retted in fresh running water tends to be pale brown, whereas material retted in stagnant swamp pools develops a reddish-brown tinge, which is attractive and leads to higher prices. The extracted fibres still have a coating of decomposing background tissue which has to be removed. In the case of Calabar piassava this coating is stripped by drawing the fibre through a cleft cut into a stick or palm petiole. In the case of Sherbro and Sulima, the retted strips are usually flogged over and drawn through a comb of pointed sticks. Fibres may also be separated and cleaned by hand. The cleanliness of the fibre has a large impact on quality and market value. Cleaned fibres may be spread out to dry in the sun for a few days. Further drying may occur under the eaves of houses or above fireplaces. Fibres which are not properly dried become mouldy and brittle and can be a fire hazard in warehouses and ships. Fibre length is an important attribute as long fibres provide more opportunities for further processing. It is also important that bundles consist of fibres of uniform length. High quality Sherbro and Sulima fibres show little variation in length and are about 1.5 m long. Although shorter fibres are acceptable, they should not be shorter than 25–30 cm. The Sherbro and Sulima fibres are normally packed in bundles of 25 kg. Calabar fibres are more variable in length and require sorting into bundles of uniform length – a tedious and time-consuming task. Traditionally, bundles of fibres of differing lengths are transported to local markets, where they are weighed and priced. The buyer then mixes fibres from different sources before trimming and tying them into uniform bundles of 70–100 cm diameter.

Palm wine from *Raphia hookeri* is mostly con-

sumed fresh, but can be distilled to make a strong alcoholic liquor.

**Genetic resources** No germplasm collections of *Raphia hookeri* are known. *Raphia hookeri* is not threatened with extinction as it occurs over a very large area and is widely protected by farmers.

**Prospects** Locally, *Raphia hookeri* will remain an important multipurpose palm, yielding various types of fibres, highly valued palm wine and a range of other products. Its importance in international trade as a source of African piassava fibre has declined sharply following the advent of plastic substitutes, but there is still demand for natural brush-fibres. This demand may even increase in the future as environmentally friendly, traditional products gain popularity.

**Major references** 2016, 5717, 5718, 5719, 5720, 5721, 5722, 5723, 5724, 5724

**Other references** 2054, 3948, 5531, 5586, 5726, 5727, 5728, 5729, 5730, 5731, 5732, 5733, 5734, 5735, 5736, 5737, 5738, 5739, 5740, 5741

**Sources of illustration** 5723 (inflorescence, fruit), 5742 (plant habit), 5743 (leaflet)

**Authors** M. Brink

## RAVENALA MADAGASCARIENSIS Sonn.

**Protologue** Voy. Indes orient. Ed. 1, 2: 223, t. 124–126 (1782).

**Family** Strelitziaceae

**Chromosome number** $2n = 22$

**Vernacular names** Traveller's palm, traveller's tree (En). Arbre du voyageur (Fr). Palmeira do viajante (Po). Arbol del viájero (Sp).

**Origin and geographic distribution** Traveller's palm is endemic to Madagascar, and naturalized in the Mascarene Islands. It is widely planted as an ornamental tree throughout the tropics.

**Uses** The traveller's palm is very commonly planted for ornamental purposes. The leaves are arranged into 2 rows, giving the impression of a gigantic fan. The vernacular names are an indication of the alleged use by travellers, who are said to have drunk rain water accumulated in the basal cup of the petiole and in the flower bracts. However, this water is often rendered undrinkable by infestation with mosquito larvae and contamination by detritus.

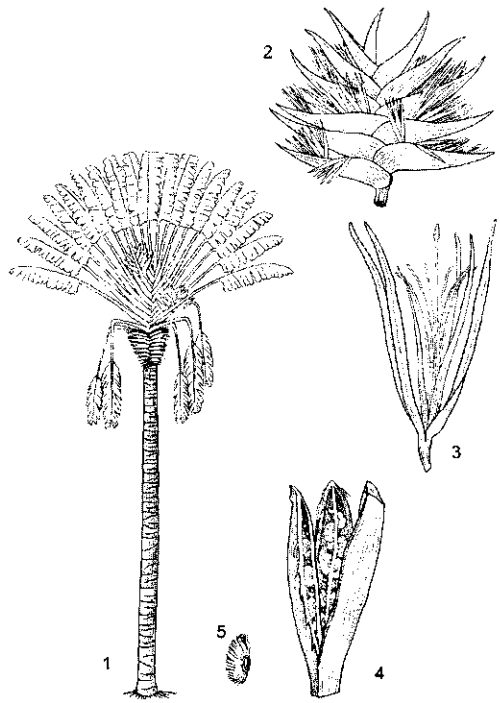
*Ravenala madagascariensis* is economically important locally along the east coast of Madagascar, where the leaves are used for roofing, the petioles for walls and the bark for floors in houses. In parts of India, the stem is used in house construction, the leaves for packing material and for roofing, and the midribs and petioles for hut walls.

Sugar can be extracted from the sap of the trunk. The seeds are edible, but mealy, and the edible arils are tasteless. The seed oil is sometimes used for cooking, and is reported to be antiseptic. The pith from the trunk is sometimes used as a fodder for livestock.

**Properties** The oil content of the seeds and arils is 4% and 68%, respectively. The oils have a fatty acid composition intermediate between palm oil and cocoa butter (oleic acid 39% and palmitic acid 34–42%) and form a possible minor source of vegetable butter. Analysis of the sterol fraction of the seed oil revealed 7 sterols, mainly β-sitosterol (65%), whereas 12 sterols have been isolated from the aril oil, mainly stigmasterol (18%), 24-methyl-5α-cholest-7-en-3-β-ol (16%), α-spinasterol (28%) and Δ-7-avenasterol (19%).

**Description** Medium-sized evergreen tree, up to 20(–30) m tall; roots rhizomatous; trunk solitary or branched at base, cylindrical, woody, ring-scarred, olive green and smooth or grey and fissured, apical third clothed by leaf bases; crown fan-like, with 20 or more leaves. Leaves alternate, distichously arranged, simple; petiole 3–6 m long, stout, channelled, with air canals, arising at 45° to axis, base cup-shaped, broadly sheathing and overlapping; blade oblong, 2.5–4(–5) m × 0.8–1.5 m, base and apex rounded, entire but often torn at the veins, glabrous, dull green, midrib sulcate, pale, with closely set, parallel veins. Inflorescence an axillary thyrse, bearing cincinnate flower clusters enclosed in distichously arranged, large, stiff, boat-shaped bracts 20–25(–30) cm long,

*Ravenala madagascariensis – wild and naturalized.*




*Ravenala madagascariensis – 1, plant habit; 2, inflorescence; 3, flower; 4, dehisced fruit; 5, seed. Redrawn and adapted by M.M. Spitteler.*

whitish. Flowers bisexual, slightly zygomorphic, 3-merous, subtended by carinate bracteoles, all flower parts creamy white; sepals free, lanceolate, subequal, up to 20 cm long, long-acuminate; petals free, lanceolate, up to 15 cm long, posterior one shorter than other 2; nectaries with copious nectar; stamens 6 in 2 whorls of 3, up to 16 cm long, anthers basifixed, dehiscing via longitudinal slits; ovary inferior, 3-locular, style long, straight, stigma with finger-like protuberances. Fruit an oblong, woody, loculicidal capsule 2–4 cm long, many-seeded. Seeds ovoid, ca. 0.5 cm long, glabrous, brown, with abundant endosperm, surrounded by a blue to purple, laciniate-lobed aril. Seedling with hypogeal germination, cotyledon single, massive, tip remaining in the seed-coat as an absorbing organ.

**Other botanical information** The monotypic *Ravenala* is one of 3 genera in the *Strelitziaceae*, the others being the monotypic *Phenakospermum* from the swamps of South America and *Strelitzia* with 5 species from southern Africa. *Strelitziaceae* is closely related to *Musaceae*, *Heliconiaceae* and *Lowiaceae*.

In eastern Madagascar, 4 forms of *Ravenala madagascariensis* have been observed on the slopes of the hills, from sea-level up to 1000 m altitude. The first form, locally called 'malama', is rather rare and grows in the understorey of undisturbed submontane rain forest. The juvenile phase is characterized by a secondarily spiral arrangement of the leaves, a long-decurrent leaf blade, the absence of a petiole, and the arrangement of the leaves to form a torus; the adult phase has a fan-like crown. The second form, 'hiranirana', is more abundant in forest gaps and disturbed primary forest, and the juvenile phase is more similar to the usual fan-like form, with well-developed petioles and a relatively wide leaf blade, and a slight and regularly alternate arrangement of the leaves, persisting in the adult phase. The third form, 'bemavo' is the most common form, growing on deforested slopes between 300–600 m altitude, and forming *Ravenala* forests; all phases show a fan-like crown. This form is mostly used for construction purposes. The fourth form, 'horonorona' grows in deforested lowland sites, on either poorly or well-drained soils, and is different from the other 3 in that it stays rather small and develops many suckers. It is the form that is most commonly cultivated.

**Growth and development** The leaves at the base of a new shoot often consist often only of sheaths. Each new leaf grows up inside the sheath of the preceding one, the blade being tightly rolled. A fully expanded leaf is often slightly unequal-sided, or the base of the blade is asymmetrical. It takes up to 10 years before first flowering, but because traveller's palm is planted for its foliage this does not distract from its ornamental value.

Every 2–3 days, a new flower opens in an inflorescence, the total number of open flowers being variable; up to 29 have been counted. The flowers normally open at night. Nectar production is copious, with maximum production at midnight. In Madagascar, traveller's palm is pollinated predominantly by several lemur species, e.g. the ruffled lemur (*Varecia variegata*) and the black lemur (*Eulemur macaco*). Lemurs appear to be highly dependent on the nectar of traveller's palm during specific times of the year. In areas outside the natural range, flowers are often visited by large bats, such as *Pteropus alecto gouldii* and *Macroglossus lagochilus*, as well as honeyeater birds (*Megaphagidae*) in Australia. The 2 abaxial petals are linked by interlocking papillae to form a tube around the anthers. At anthesis, they separate with an explosion that sheds the pollen onto a potential pollinator. Autogamy treatments

revealed that *Ravenala madagascariensis* is a facultative self-fertilizer.

**Ecology** Traveller's palm prefers sheltered, warm and humid and per-humid areas near the coast, from sea-level up to 450 m altitude, but it can be found up to 1000 m.

**Propagation and planting** Propagation is by seed and suckers. Seed is best sown in a moist, sandy soil at 20°C. Seedlings of 2–6 months old are planted in a rich, deep, loamy soil in full sunlight, incorporating organic matter at planting to prevent drying of the roots. Suckers grow at irregular intervals, close to the parental stem. Rooted suckers are separated at the beginning of the rainy season, and are directly planted into fertile soil for quick growth.

**Diseases and pests** *Ravenala madagascariensis* is a host of the fungus *Colletotrichum gloeosporioides*, which causes leaf spot disease of, for example, areca nut palm (*Areca catechu* L.) in India. There the roots of traveller's palm are also attacked by the root-knot nematode *Meloidogyne incognita*.

**Genetic resources** As *Ravenala madagascariensis* is widely planted throughout the tropics, there seems to be no risk of genetic erosion, although the genetic diversity of plants in cultivation is unknown. No germplasm collections are known.

**Prospects** As traveller's palm is a popular ornamental tree that is widely grown, the development of cultivars with different habits might be a good trade option. As deforestation in Madagascar proceeds at an alarming rate, protection of the tree from uncontrolled cutting may soon be necessary.

**Major references** 2184, 5423, 5424, 5425

**Other references** 4141, 5101, 5417, 5418, 5419, 5420, 5421, 5422

**Sources of illustration** 4141 (flower), 5417 (plant habit), 5426 (inflorescence, dehisced fruit, seed)

**Authors** G.H. Schmelzer

## SCLEROCARYA BIRREA (A.Rich.) Hochst.

**Protologue** Flora 27, Bes. Beil.: 1 (1844).

**Family** Anacardiaceae

**Chromosome number** $2n = 26$

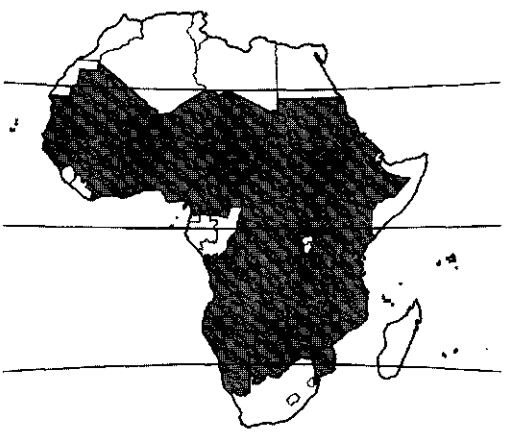
**Synonyms** *Sclerocarya caffra* Sond. (1850), *Poupartia caffra* (Sond.) H.Perrier (1944), *Poupartia birrea* (A.Rich.) Aubrév. (1950).

**Vernacular names** Marula, cider tree (En). Prunier d'Afrique, sclérocarya à bière, prunier jaune (Fr). Canhoeiro, morula (Po). Mng'ongo, mng'ong'o, morula, mungango (Sw).

**Origin and geographic distribution** Marula occurs throughout most of sub-Saharan Africa outside the humid forest zone, from Mauritania and Senegal to Ethiopia and Eritrea, south to Namibia, Botswana, Zimbabwe, Mozambique, South Africa and Swaziland. It is also present, possibly introduced, in Madagascar and has been introduced to Mauritius and Réunion. It is grown as an experimental crop in Israel and has been introduced to Australia, India and Oman.

**Uses** Marula provides diverse benefits at subsistence level and yields traded, and increasingly commercialized, commodities. The main product is the fruit ('marula plum'), a dietary item for over 1000 years. The flesh of the raw fruits is consumed, the skin being discarded, or the juice sucked from them. Kernels extracted from the fruits are also eaten raw. Fermenting the fruit at household level produces an alcoholic beverage ('marula beer') which is either consumed directly or distilled into a strong liqueur. The boiled juice is used to flavour and sweeten porridge. The kernels are crushed and used to make cakes or biscuits or as a soup ingredient, or oil is extracted from them and used as a meat preservative. The oil is also used for cooking and skin care.

Considerable medicinal significance is attached to the tree, especially its bark (including that from roots) and leaves. Conditions treated with decoctions or pastes containing bark or leaf ingredients include infections and parasitic diseases, problems with the digestive tract and injuries. Bark decoctions are administered orally or as enemas to treat diarrhoea and dysentery. They are also used to treat stomach ailments,



*Sclerocarya birrea – wild.*

fever and ulcers. Roots are used to treat sore eyes. The skin of the fruit is used to treat blisters caused by hairy caterpillars.

*Sclerocarya birrea* foliage is eaten by livestock although it is never a major source of browse. Apart from fallen fruits, use is intermittent except in times of general feed shortage when herdsmen lop branches to make foliage accessible. Additional livestock benefits are shade from the tree and the quality of forage grasses beneath it. The tree yields a utility timber which was commercially important in the past (Senegal, South Africa). The ease of working the wood with simple tools, combined with its large size for a dryland tree, explains its traditional popularity for the production of mortars, bowls and drums. It is also used as fuelwood.

In South Africa, the bark is used to prepare a mauve, pink, brown or red dye, the colour depending on methods used. Ink has been made by dissolving gum from the bark in water and adding soot.

**Production and international trade** Over the last 20 years, commercial products from southern Africa based on marula fruits have been marketed. Most prominent is a liqueur ('amarula') but a beer, wine and pasteurized juice have also been produced. There have been initiatives to market jams and jellies with marula as the characteristic ingredient. Marula oil is extracted for export as a cosmetic product in Namibia. Commercial use probably accounts for well over 600 t of juice per year.

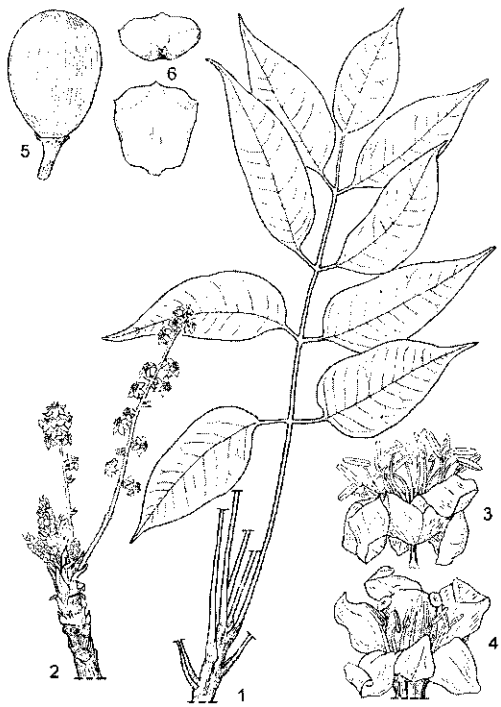
**Properties** There are high ascorbic acid concentrations in the fruit skin (150–250 mg/100 g), flesh (150–400 mg/100 g) and juice (100–200 mg/100 g). Kernels contain per 100 g dry matter: protein (20–35 g), fat (55–65 g), phosphorus (0.7–1.9 g) and have an energy value of 25 MJ/kg. The oil is rich in oleic acid (64–74.5 g/100 g) which gives good oxidative stability, palmitic acid (11–17.5 g/100 g), stearic acid (5–11 g/100 g) and linoleic acid (4–9 g/100 g). The main amino acids are glutamic acid (18–27 g/100 g protein), arginine (11–16 g/100 g protein) and aspartic acid (5.5–8 g/100 g protein).

The potent tyrosinase inhibitor 2-hydroxy-4-methoxybenzaldehyde has been isolated from marula bark, and also (–)-epicatechin-3-galloyl ester, which showed secretagogue activity on rat colon. Bark and leaf extracts showed antibacterial activity against *Enterococcus faecalis*, *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*, substantiating the ethnobotanical use of marula for bacteria-related diseases.

In West Africa, the fodder contains per 100 g dry matter: calcium (3.1 g), magnesium (2.4 g) and potassium (1.2 g). Low values of crude protein (8.3 g) and digestible protein (4.7 g) and a low nutritional ratio (4.7 g digestible protein associated with 630 kJ net energy per 100 g dry matter) signify poor fodder quality.

The sapwood is thin and paler than the pale pinkish to pale reddish-brown heartwood. The wood texture is coarse but even; the air-dry density is 590 kg/m$^3$. However, strength of the wood is low, durability poor, and the wood is liable to distort during drying. In South Africa its commercial use was banned in 1962 when the tree became protected.

**Description** Usually dioecious, small to medium-sized tree, usually 9–12 m tall but occasionally up to 18 m, with a taproot and sturdy lateral roots extending as far as 30 m; bole short (usually ca. 4 m), up to 120 cm in diameter; bark pale silvery or purplish-grey on small individuals, rough on large individuals, with flat, roundish scales; crown rounded, with rather dense foliage, spreading widely in large, old trees; branchlets stout, the leaves clustered at the ends. Leaves alternate, 8–38 cm long, imparipinnate with 3–18 pairs of leaflets; stipules absent; petiole, rachis and petiolules glabrous, channelled; lateral leaflets subsessile or with petiolules up to 3 cm long, terminal leaflet with a petiolule up to 5 cm, leaflets round to oblong-elliptical or elliptical, 1–9 cm × 0.5–3.5 cm, length increasing up the rachis, asymmetrical and cuneate or rounded at base, obtuse, acute, acuminate or acuminate-caudate at apex, margin entire or (in juvenile state) dentate-serrate, glabrous, with 6–16 pairs of lateral veins. Male inflorescence a terminal or axillary, drooping raceme 5–22 cm long, with flowers in groups of 3–4 towards the base but solitary towards the apex; female inflorescence reduced, subterminal and spiciform, with 1–2(–3) flowers. Flowers unisexual, regular, 4–5-merous; pedicel 0.5–5 mm long in male flowers, 0.5–1 mm long in female flowers; sepals free or almost free, ovate-round, 2–3.5 mm × 1–2.5 mm, spreading, usually reddish; petals free, obovate to oblong-ovate, 4–6 mm × 2.5–4 mm, becoming reflexed in male flowers, remaining erect in female flowers, yellowish to reddish; male flowers with (10–)15–25(–30) stamens 3–4 mm long, inserted round a subentire, yellow disk; female flowers with a superior, subglobular, 2–3(–4)-celled ovary immersed in the disk, crowned by 2–3 short, lateral styles ending in a capitate stigma, and 15–26 staminodes. Fruit an obovoid to subglobular drupe 3–3.5 cm in




*Sclerocarya birrea – 1, twig with leaf; 2, twig with male inflorescences; 3, male flower; 4, female flower; 5, fruit; 6, stones in top and side view. Redrawn and adapted by M.M. Spitteler.*

diameter, yellow at maturity, on a 10–15 mm long pedicel; skin thick, mesocarp fibrous, fleshy and juicy and adherent to the hard stone 2.5–3 cm × 1.5–2.5 cm with (1–)3(–4) compartments, each with a flattened seed. Seeds obclavate, compressed, 15–20 mm × 4–8 mm × 2.5 mm, with papyraceous brownish testa; cotyledons planoconvex. Seedling with first leaves trifoliolate having sessile, pinnately veined leaflets with dentate margins.

**Other botanical information** *Sclerocarya* is a strictly African/Madagascan genus and all closely related genera are African. It is closely related to *Poupartia*, a Madagascan and Indian Ocean genus of 5 species into which *Sclerocarya* is sometimes sunk. *Sclerocarya* comprises only 2 species, *Sclerocarya gillettii* Kokwaro being a small tree or shrub endemic to Kenya. Three subspecies of *Sclerocarya birrea* are distinguished: subsp. *birrea*, subsp. *caffra* (Sond.) Kokwaro and subsp. *multifoliolata* (Engl.) Kokwaro. Subsp. *caffra* occurs widely in southern Africa and is distinguished by its acuminate or cuspidate leaflets and by its lower leaflets having petiolules 5–30 mm long (in subsp. *birrea* leaflets obtuse to acute and petiolules up to 5 mm). The large number of leaflets, (25–)29–37, distinguish subsp. *multifoliolata*, which is restricted to Tanzania, perhaps also in Kenya. Subsp. *birrea* occurs north of the equator and extends south into Kenya and Tanzania.

**Growth and development** Marula is fast growing, reaching 3.5 m in 8 years on the 600 mm mean annual rainfall isohyet (Bambey, Niamey). Mean heights and diameters of planted trees 4–5 years old in Israel were 4.1–6.2 m and 13–18 cm (30 cm from the ground), respectively. Wild trees in Mali, estimated 11–12 years and 32 years old, were 8.2 m and 6.9 m tall and 28 cm and 45 cm in diameter, respectively. The trees can be coppiced, regenerating rapidly.

Planted trees first flowered and produced fruits in Israel at an age of 3 years. Although widely described as a dioecious species, occasional female flowers occur among the male flowers of a few otherwise male trees. Flowering takes place in the dry season when the trees are leafless. North of the equator the fruits mature and fall at the end of the dry season as the trees flush. In the southern part of the range fruits remain on the trees longer, into the rainy season.

**Ecology** Marula is a constituent of low elevation (mostly <1600 m) vegetation types from tree or shrub grassland to woodland. In the drier parts of its range, marula individuals are often taller than other species growing with them. Widely spaced single individuals, retained as fruit trees when other species are removed, often characterize farmland and parkland landscapes.

The species is associated with a strongly seasonal rainfall pattern. Mean annual rainfall is usually 500–1200 mm and mean monthly rainfall >50 mm occurs in 4–7 months. Populations occur in more humid conditions (6–9 months >50 mm; mean annual totals 1200–1600 mm) in the transition between the Guineo-Congolian and Zambezian regions and in more arid conditions (2–3 months >50 mm; mean annual totals 250–500 mm) in the Sahelian region. Populations north of the equator occur in higher temperatures (mean annual temperature generally >26°C) than those further south (mean annual temperature generally 18–25°C). The range within the tropics is almost entirely frost-free but populations in southeastern Zimbabwe, and south into South Africa experience occasional frost. This is reported to cause major branch loss when severe (–4°C). Temperatures rise above 40°C regularly during April and May in West Africa and absolute maxima above 45°C (54°C in Timbuktu, Mali) are

recorded from the West African part of the range. The soils where marula occurs range from basalts and basement complex rocks to Quaternary deposits, almost always described as light- to medium-textured, well-drained sands and loams. References to presence on escarpments and rocky hills underline the need for good drainage. Heavy soils are unsuitable. It can tolerate seasonal waterlogging, and experience with planted stands in Israel indicates tolerance of a salinity level of 4 dS/m in irrigation water.

**Propagation and planting** Although viability of marula seeds is lost rapidly in open storage, seeds store well in air-dry storage at cool temperatures. The stones (seed with endocarp) are used to raise seedlings in the nursery. Estimated numbers per kg range from 300 (Burkina Faso) to 400–500 (West Africa and Tanzania). Stones are pretreated to loosen the plugs (opercula) that close the germination apertures and allow the radicle and hypocotyl to grow out. Various methods are used. Pretreating stones by putting them in boiling water, removing the heat source and leaving them immersed for 24 hours has given 53% success (Mali). Physically loosening the plugs of freshly cleaned stones gave 70% success after one week and 85% after two weeks (Tanzania). In Burkina Faso, fresh stones are soaked in water for 48 hours before sowing into containers, giving 80% germination in 16 days, the first germination being recorded in 4 days.

Nursery media recommended are 3:1:1 or 1:1:1 mixtures of earth, coarse sand and manure, and well-drained sandy loam. In Burkina Faso, the nursery period lasts 11 weeks, by which time seedlings are 20–30 cm tall. During the nursery period, watering takes place twice daily and containers are relocated (or the seedlings root-pruned) monthly. Shading is provided for 2 days after repotting or pruning.

Propagation using large branch or stem pieces (10 cm × 2 cm), root suckers and grafting is also possible.

**Management** Irrigated orchards of marula are maintained in Israel, water being provided every 1–2 days (summer) or every 3–5 days (winter).

**Diseases and pests** The most frequently reported pests are loranthaceous hemiparasites including *Agelanthus crassifolius* (Wiens) Polhill & Wiens, *Helixanthera garciana* (Engl.) Danser, *Pedistylis galpinii* (Schinz ex Sprague) Wiens and *Tapinanthus globiferus* (A.Rich.) Tiegh. Fruit pests include *Carpophilus hemipterus* (*Coleoptera*: *Nitidulidae*), *Cryptophlebia leucotreta* (*Lepidoptera*: *Olethreutidae*) and the fruit fly *Ceratitus cosyra* (*Diptera*: *Tripetidae*).

**Harvesting** Traditionally, fruits are harvested off the ground. The fruit falls while still green and ripens on the ground in up to 10 days, turning yellow in the process.

**Yield** Estimates of seasonal fruit crops from individual trees in southern Africa have been made assuming a mean fruit fresh weight of 18 g. Values per tree range from 315 kg (17,500 fruits) to 1643 kg (91,300 fruits). Fruits with a fresh weight as large as 80–100 g are known.

**Handling after harvest** Fruit damage results from storage below 9°C, but satisfactory product quality is maintained over 14 days when stored at temperatures of 12–20°C.

**Genetic resources** There are small orchards in Israel which have been established with seed from natural stands in Botswana. Germplasm from these, from additional Botswana stands, and from South Africa (Kruger National Park), was used for RAPD (random amplified polymorphic DNA) analysis. The analysis confirmed the presence of genetic differences between clones but did not indicate consistent differences between populations of Botswanan and South African origin. A recent study of 15 populations south of the equator (Namibia to Kenya) and one from West Africa (Mali) has used both RAPD and restricted fragment length polymorphism analyses. The results indicate patterns of variation both between and within populations.

**Breeding** Clones have been selected for individual fruit size and quality and yield per tree with a view to registration as cultivars. Tree growth and fruit abscission time are further criteria suggested by experience in trial orchards. DNA fingerprints have been advocated as registerable characteristics for morphologically indistinguishable genotypes.

**Prospects** There is continuing traditional importance of marula through most of tropical Africa and extensive scope for commercial initiatives. Investigation of genetic and product quality variation has centred on the southern extremity of the geographic range and attention to germplasm from more locations is appropriate, e.g. planned large-scale trials to be established in Tanzania.

More research is needed into fruit storage procedures and the use of kernel material as a commercial by-product of fruit processing. The traditional uses of bark to treat bacteria-related diseases often have detrimental effects on marula populations. Leaf material is also useful as antibacterial

agent, and the use of leaves as a more sustainable resource may be further developed and promoted.

**Major references** 3815, 5640, 5644, 5645, 5646, 5647, 5648, 5649, 5650, 5651

**Other references** 2105, 2166, 4191, 5641, 5652, 5653, 5654, 5655, 5656, 5657, 5658, 5659, 5660, 5661, 5662, 5663, 5664, 5665, 5666

**Sources of illustration** 5641 (twig with leaf, twig with male inflorescences, male flower, female flower), 5642 (fruit), 5643 (stones in top and side view)

**Authors** John B. Hall

## SOLANUM AETHIOPICUM L.

**Protologue** Cent. pl. II: 10 (1756).

**Family** Solanaceae

**Chromosome number** $2n = 24$

**Synonyms** *Solanum gilo* Raddi (1820), *Solanum incanum* auct. non L.

**Vernacular names** Scarlet eggplant, African eggplant, bitter tomato (En). Aubergine écarlate, aubergine africaine, tomate amère (Fr). Jilo (Po). Ngogwe, nyanya chungu (Sw).

**Origin and geographic distribution** *Solanum aethiopicum* was domesticated from the wild *Solanum anguivi* Lam., via the semi-domesticated *Solanum distichum* Schumach. & Thonn., both of which are found throughout tropical Africa, in disturbed vegetation and gardens, respectively. *Solanum aethiopicum* is grown throughout tropical Africa and South America, and occasionally elsewhere, e.g. in southernmost Italy.

**Uses** Scarlet eggplant is important as an immature fruit vegetable cooked in stews. As a leaf vegetable it is cooked in the same way as spinach (*Spinacia oleracea* L.). The fruits of non-bitter cultivars are eaten raw; fruits of bitter cultivars are used as medicine and spice. Medicinal applications include the use of roots and fruits as a carminative, sedative and to treat colic; leaf juice as a sedative to treat uterine complaints; an alcoholic extract of leaves as a sedative, anti-emetic and to treat tetanus after abortion; and crushed and macerated fruits as an enema. Scarlet eggplant is sometimes cultivated as an ornamental, and is used as a rootstock for eggplant (*Solanum melongena* L.) in Japan and for plant breeding because it has some disease resistance.

*Solanum aethiopicum – planted.*

**Production and international trade** Scarlet eggplant is a very important traditional garden vegetable consumed throughout tropical Africa, second only to West African okra (*Abelmoschus caillei* (A.Chev.) Stevels) in Côte d'Ivoire, and to tomato in Ghana. Although reliable statistics for much of sub-Saharan Africa are not available, annual production of fruits is about 8000 t in Senegal, 60,700 t in Côte d'Ivoire and 4500 t in Burkina Faso. Commercial production to supply cities is increasing, as is export to Europe from many African countries. Small-scale growers account for about 80% of total fruit production.

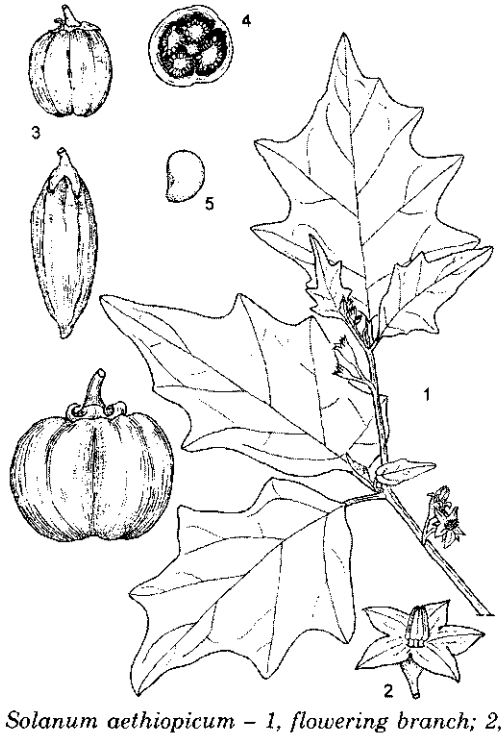
**Properties** Fruits, when picked unripe and cooked, have considerable nutritional value; the seeds are rich in fats and proteins. Leaves have a protein content and amino acid composition similar to spinach. However, they are potentially toxic, containing oxalate (ca. 9% in leaf protein concentrate), solasodine (0.3–1.2 mg/g fresh leaf) and similar alkaloids, but these compounds can be reduced by proper cooking. Betulin and sterolin (sitosterol glucoside) have been isolated from the fruits.

Fresh leaves contain per 100 g: water 81–87 g, protein 3.1–5.3 g, fat 0.3–0.5 g, carbohydrates 6.6–10.3 g, fibre 1.9–2.5 g, ash 2.0–3.2 g, calcium 162–537 mg, phosphorus 37–99 mg, iron 6–16 mg, β-carotene equivalent 6 mg, thiamine 0.2 mg, riboflavin 0.4 mg, niacin 1.8 mg and ascorbic acid 36–165 mg; the energy value is 159–213 kJ/100 g.

Fresh fruits contain per 100 g: water 65–94 g, protein 0.7–1.6 g, fat 0.1–1.0 g, carbohydrates 5.7–7.7 g, fibre 1.3–2.2 g, ash 0.3–0.7 g, calcium 11–103 mg, phosphorus 7–48 mg, iron 0.5–3 mg, β-carotene equivalent 0.03–0.35 mg, thiamine 0.02–0.07 mg, riboflavin 0.04–0.06 mg, niacin 0.5–0.8 mg and ascorbic acid 5–176 mg; the

energy value is 121–134 kJ/100 g.
Dried leaves contain about 21% protein, with alanine 6.8%, arginine 6.9%, aspartic acid 9.3%, glutamine 13.0%, glycine 4.9%, histidine 2.8%, isoleucine 5.1%, leucine 9.4%, lysine 7.2%, methionine 1.6%, phenylalanine 6.5%, proline 6.0%, serine 5.0%, threonine 4.6%, tyrosine 4.9% and valine 6.0%.
Dried fruits contain about 11% protein, with alanine 5.4%, arginine 5.5%, aspartic acid 10.4%, glutamine 19.9%, glycine 4.0%, histidine 4.1%, isoleucine 5.2%, leucine 8.1%, lysine 7.4%, methionine 1.0%, phenylalanine 5.0%, proline 5.6%, serine 5.2%, threonine 4.2%, tyrosine 3.2% and valine 5.8%.
Several sesquiterpenoids have been isolated from the roots of scarlet eggplant. Among these compounds are lubimin and epilubimin, which have antifungal activity.

**Description** Shrub to perennial or annual herb, up to 200 cm tall, often much-branched; root system extending both vertically and laterally; branches and leaves with or without prickles and stellate hairs. Leaves alternate, simple; stipules absent; petiole up to 11 cm long; blade broadly ovate, (6–)12–30 cm × (4–)7–21 cm, obtuse or cordate at base, acute to obtuse at apex, slightly to deeply lobed at margin, pinnately veined; upper leaves smaller, narrower, less lobed and often subopposite. Inflorescence a lateral, racemose cyme, up to 5(–12)-flowered; peduncle often short or even absent, rachis short to long. Flowers bisexual, regular, (4–)5–8(–10)-merous; pedicel (2–)4–12(–15) mm long, up to 27 mm long in fruit; calyx campanulate, lobes 4–10 mm long; corolla stellate, 6–15 mm long, white, sometimes pale purple; stamens inserted near the base of the corolla tube and alternate with corolla lobes, filaments short and thick, anthers connivent, yellow, opening by terminal pores; ovary superior, 2–6-celled, style as long as or slightly longer than stamens, stigma small, obtuse. Fruit a depressed globose to globose, ellipsoid, ovoid or fusiform berry 1–6 cm long, smooth to grooved, red or orange, usually many-seeded. Seeds lenticular to reniform, flattened, 2–5 mm in diameter, pale brown or yellow. Seedling with epigeal germination; cotyledons thin, leafy.




*Solanum aethiopicum – 1, flowering branch; 2, flower; 3, different fruit types; 4, fruit in cross section; 5, seed.*
*Redrawn and adapted by M.M. Spitteler.*

**Other botanical information** The genus *Solanum* comprises over 1000 species and is almost cosmopolitan, with at least 100 indigenous African species. *Solanum aethiopicum* belongs to subgenus *Leptostemonum* section *Oliganthes*, which comprises about 45 species. Four cultivar-groups are recognized within *Solanum aethiopicum*: Aculeatum Group, with mature leaves covered with stellate hairs, prickly stems and leaves, fruit subglobose, furrowed, 3–8 cm in diameter, fruits and leaves not eaten; Gilo Group, with mature leaves covered with stellate hairs, not prickly, fruit subglobose to ellipsoid, 2.5–4 cm long, only fruits eaten; Kumba Group, with mature leaves glabrous apart from minute glandular hairs, not prickly, fruit depressed globose, deeply furrowed, 5–10 cm broad, fruits and leaves eaten; and Shum Group, with mature leaves glabrous apart from minute glandular hairs, not prickly, fruit subglobose, 1–2 cm in diameter, only leaves eaten. *Solanum aethiopicum* Aculeatum Group does not occur in Africa, but is sometimes cultivated as an ornamental elsewhere; Gilo Group is cultivated from Senegal east to Somalia, and south to South Africa; Kumba Group is characteristic of sub-Sahelian Africa from Mauritania to northern Nigeria; and Shum Group is cultivated sporadically from Togo to Sudan and to Zambia, but especially in Cameroon and Uganda. Intermediate forms occur, especially between Gilo Group and the others.
Plants of all these cultivar-groups can be crossed

mutually as well as with *Solanum anguivi* and *Solanum distichum* to produce fully fertile hybrids, and therefore might be considered as a single biological species. The non-prickly semi-domesticated *Solanum distichum* may well be treated as a cultivar-group of the prickly wild progenitor *Solanum anguivi*.

**Growth and development** Germination is epigeal, after which the cotyledons expand and the first true leaves form a rosette. New leaves rapidly increase in size. As the first flowers are initiated, branching and subsequent production of smaller leaves occurs. Flowering starts (40–)70–100 days after sowing for Kumba Group and Shum Group and 90–110 days for Gilo Group. Unlike *Solanum melongena*, all flowers are functionally bisexual and can set fruit. They are bee-pollinated, mainly by the genera *Exomalopsis* and *Apis*. Cross-pollination between different cultivars or cultivar-groups, and with *Solanum melongena*, is likely when these are grown near each other. The hybrids between *Solanum aethiopicum* and *Solanum melongena*, however, bear few or no fruits or seeds. For breeding purposes, flowers must be bagged to prevent cross-pollination, and must be emasculated to prevent self-pollination.

Growth and flowering may continue indefinitely, but are suppressed once sufficient fruits have set. The small fruits of *Solanum anguivi*, *Solanum distichum* and *Solanum aethiopicum* Shum Group ripen rapidly, turning red; they are eaten by birds, which disperse the seeds. The much larger fruits of *Solanum aethiopicum* Gilo Group and Kumba Group ripen more slowly and stay firm even when red, and can be stored for weeks or even months. In the dry season, plants may become dormant and appear to be dead, but can revive in the next rainy season, although they are then not very productive.

**Ecology** *Solanum aethiopicum* Gilo Group thrives in full sun in woodland savanna on fairly deep and well-drained soils with pH 5.5–6.8, and in temperatures of 25–35°C during the day and 20–27°C at night. Kumba Group grows in hotter conditions (up to 45°C day temperature) with an air humidity sometimes as low as 20%, especially if irrigated. Shum Group can grow in wetter conditions. None of these cultivar-groups survive cold or very wet conditions. Waterlogging is not tolerated. Some tolerance of irrigation-induced salinity is reported from Senegal.

**Propagation and planting** Seeds should be taken from fully ripe fruits, washed, and then dried on cloth or paper within 2 days. They should not be exposed to direct sunlight. Seeds are orthodox and can be stored dry and cold, e.g. above silica gel in a sealed container in a refrigerator. Seeds also store well within air-dried fruits. One thousand seeds weigh 2–4 g.

Germination takes 1–2 weeks for Gilo Group, but only 3–7 days for Kumba Group. Treatment with gibberellic acid (500 ppm for 24 hours) and incubation in fluctuating high temperatures (25/35°C) hastens germination. Seeds are sown in sandy soil in nursery beds or boxes. Young seedlings are transplanted to the field after 30–35 days, when they have 5–7 leaves and are 15–20 cm tall. They are often planted at a spacing of 0.5 m in rows 0.5–1 m apart, either on flat land or on ridges. Propagation by stem cuttings *in vitro* is also successful.

**Management** Manual preparation of the soil and hand weeding are sufficient, but large-scale production of scarlet eggplant in Senegal necessitates the use of machines for soil preparation. Plants do not need staking. If possible, 15:15:15 or 10:10:20 NPK fertilizer should be applied at 125 kg/ha 10 days after transplanting and at 50 kg/ha at first flowering, and then at monthly intervals. Soluble fertilizers may be fed by drip irrigation. Farm or poultry manure can be applied at a rate of 1–2 kg/m$^2$. Plants grown as leaf vegetables (Kumba and Shum Groups) require extra nitrogen after each harvest of leaves. Kumba Group plantations should be irrigated regularly (5–10 mm/day of water), as should those of Gilo Group after fruit set in the dry season. Soil-borne diseases and pests are controlled by crop rotation (e.g. with amaranth, groundnut or onion).

**Diseases and pests** The most serious soil-borne diseases of scarlet eggplant are wilt caused by *Pseudomonas solanacearum* (*Ralstonia solanacearum*), collar rot caused by *Sclerotium rolfsii*, *Verticillium dahliae*, and root-knot nematodes (*Meloidogyne* spp.). Crop rotation is necessary since no effective resistance is available, and chemical treatments are impracticable. Root-knot nematodes are less serious on heavy soils especially when irrigated. In Tanzania the chilli veinal mosaic virus (ChiVMV) spread by the green peach aphid (*Myzus persicae*) may cause considerable damage. Spider mites (*Hemitarsonemus* and *Tetranychus*) are a serious problem in Kumba Group in Senegal, but can be controlled by acaricide spray. Other serious pests include grasshoppers (*Zonocerus* sp.), fruit and flower borers (*Leucinodes* and *Scrobipalpa*), leaf hopper *Jacobiasca lybica* and caterpillars of *Selepa*

*docilis*.
*Solanum aethiopicum* Aculeatum Group provides some resistance to *Fusarium* and *Pseudomonas* wilt, and is used as a rootstock for eggplant (*Solanum melongena*) in Japan.

**Harvesting** Both leaves and fruits are harvested manually. Leaves of Kumba Group are picked from young plants before flowering. Shoots with several leaves and flower buds are picked repeatedly throughout the wet season in Shum Group, keeping the plants short. Fruits of Gilo and Kumba Groups are cut when full sized but still green, or slightly orange, which in rainfed crops is towards the end of the wet season. Irrigated crops may be harvested year-round.

**Yield** The preferred weight for Gilo Group fruits is 30–40 g; one plant may produce 4 kg, and yields are 5–8 t/ha without irrigation and 12–20 t/ha with irrigation, although 50(–70) t/ha is possible. Fruits of Kumba group have mean weights of 70 g to 120 g, sometimes even over 200 g; yield is 10–20 t/ha. Shum Group yields up to 5 harvests of about 3 kg/m$^2$ of leafy shoots in the rainy season.

**Handling after harvest** Fresh leaves are taken immediately to market. Fruits free of rot or damage can be transported long distances, and can be stored for several weeks or even months under airy, dry conditions. Provided that fruits are of good quality, standardization is not necessary; market women often mix different batches of fruits to make an attractive display. However, fruits for export are sorted and graded after collection from local markets, and then stored in cold rooms. Fruits and leaves are not normally processed or preserved for long periods.

**Genetic resources** The wealth of genetic diversity maintained by small-scale farmers throughout Africa is threatened by large-scale commercialization of a few cultivars, such as 'Sodefel' (Gilo Group) in Côte d'Ivoire and 'Soxna' (Kumba Group) in Senegal, often in monocultures. Extensive collections of genetic resources were made under the aegis of the International Board for Plant Genetic Resources (IBPGR), now the International Plant Genetic Resources Institute (IPGRI), from 1981–1986. Duplicates of these collections were sent to Europe and some were regenerated and evaluated there and elsewhere. In 2001, efforts were started to regenerate and evaluate all the collections as part of the EGGNET project. Plant breeders in Africa also maintain some genetic resources.

**Breeding** Very little breeding has been undertaken, but small-scale farmers have selected many diverse cultivars of *Solanum aethiopicum*. The nutritional value and yield potential of the fruits are of paramount importance. Other attributes selected for include fruit flavour, degree of bitterness, colour, pattern, size, shape, skin toughness, shelf life, earliness and duration of harvest season, plant architecture and fruit location, as well as flavour, size and ease of harvest of the leaves. In general, breeding objectives for agronomic attributes have yet to be defined and pursued, but in Senegal mite-resistant hairy cultivars have been bred in Kumba Group. Resistance to nematodes and insects, such as flower borers, is urgently needed. Tolerance or resistance to various pests and diseases is being sought amongst wild relatives of *Solanum aethiopicum*, and more especially *Solanum melongena*, and crosses between these two and other species have produced many hybrids, some of which are fertile.
DNA and other markers have revealed relatively little molecular diversity within *Solanum aethiopicum* or its immediate progenitors, although morphological diversity and its inheritance have been studied intensively; wild-type characters such as prickles, hairs and long racemose cymes are often dominant.

**Prospects** *Solanum aethiopicum* cultivar-groups Gilo, Kumba and Shum are important vegetables throughout rural tropical Africa. As they can be comparatively easily stored and transported, they are increasingly important market garden products for the growing urban population.

**Major references** 2003, 2020, 2108, 5780, 5781, 5782, 5783, 5784, 5785, 5786

**Other references** 5787, 5788, 5789, 5790, 5791, 5792, 5793, 5794, 5795, 5796, 5797, 5798, 5799, 5800, 5801, 5802, 5803, 5804, 5805, 5806

**Sources of illustration** 2020

**Authors** R.N. Lester & A. Seck

## SPATHODEA CAMPANULATA P.Beauv.

**Protologue** Fl. Oware 1: 47, t. 27 (1805).

**Family** Bignoniaceae

**Chromosome number** $2n = 26, 36, 38$

**Synonyms** *Bignonia tulipifera* Thonn. (1829), *Spathodea tulipifera* (Thonn.) G.Don (1838), *Spathodea nilotica* Seem. (1865).

**Vernacular names** African tulip tree, Nandi flame, fountain tree (En). Tulipier du Gabon, arbre-flamme (Fr). Tulipeira-do-Gabão (Po). Kifabakazi (Sw).

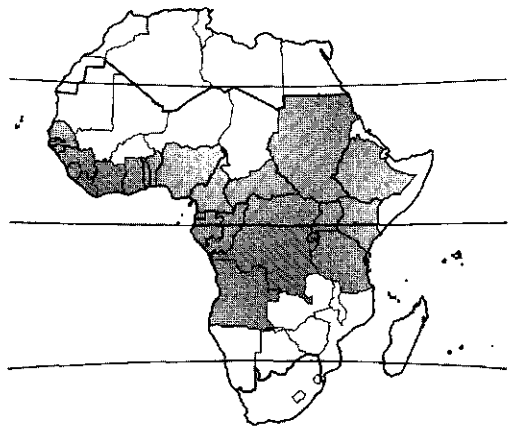
**Origin and geographic distribution** African tulip tree is native of West and Central Africa, and western East Africa, from southern Senegal east to western Kenya and Tanzania, and south to northern Angola and southern Democratic Republic of Congo. Elsewhere in tropical Africa it is planted as an ornamental, e.g. in Cape Verde, Zimbabwe and Madagascar. African tulip tree is widely grown in tropical and subtropical regions outside Africa. It has become naturalized and is an important component of secondary vegetation, e.g. in Mexico and Puerto Rico, and is considered a weed in Guam and Hawaii.

**Uses** African tulip tree is planted as an ornamental, a wayside tree and shade tree. It is used for soil improvement, reafforestation, erosion control and land rehabilitation, and as a live fence. Its dense crown does not allow intercropping, but its leaves make a useful mulch. It has been used as a shade tree in coffee plantations. In teak plantations, African tulip tree can be used to attract initial populations of teak defoliator (*Hyblaea puera*), which can then easily be destroyed.

*Spathodea campanulata* has many medicinal uses both where it is native and introduced. Extracts of bark, leaves and flowers are used to treat malaria, HIV, diabetes mellitus, oedema, dysentery, constipation, gastrointestinal disorders, ulcers, skin diseases, wounds, fever, urethral inflammation, liver complaints and as a poison antidote. It may be effective as a malaria prophylactic and in the control of *Aedes* mosquitoes.

In West Africa, the wood is used for carving, but considered inferior for other purposes. In Ethiopia, it is used as firewood and to produce charcoal. Plywood seems the only widespread commercial use for the timber, traded as African tulip (En) or tulipier (Fr); African tulip tree is grown as a plantation crop for this purpose in the Philippines. The seeds are eaten in many parts of Africa. The flower buds contain a reddish sap, and are used as water pistols by children.

**Properties** Medical research has concentrated on the effects of *Spathodea campanulata* on diabetes, malaria and schistosomiasis. A decoction of stem bark showed hypoglycaemic activity in mice, but had no influence on insulin levels. In tests on *Plasmodium berghei berghei* in mice, the hexane and chloroform extracts of stem bark showed blood schizontocidal action, and the chloroform extract demonstrated some prophylactic properties. The extracts not only suppressed parasitaemia but also prolonged the lifespan of mice. An aqueous alcoholic extract of the leaves also showed some antimalarial properties.



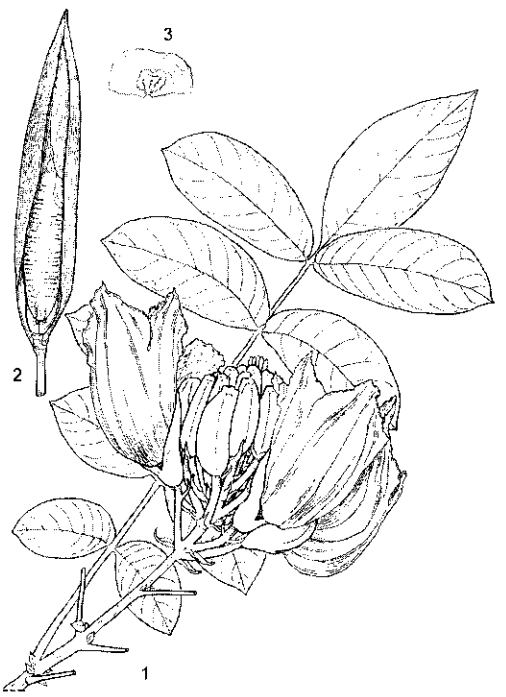
*Spathodea campanulata* – *wild.*

Extracts have been tried as a molluscicide; several of these proved effective against *Biomphalaria glabrata* in Brazil, but in Swaziland they were the least effective of all extracts tested against *Bulinus africanus*, the schistosomiasis (bilharzia) vector. As a fungicide they had little effect on damping-off caused by *Pythium aphanidermatum*, but they were effective against bean rust caused by *Uromyces appendiculatus*. The extracts showed larvicidal properties against the mosquito *Aedes fluviatilis*, a vector of Rift Valley fever.

Of the many compounds isolated from the wood, bark and leaves the most promising are ursolic acid and its derivatives, which are believed to play a role in the antimalarial activity of the bark extract.

The wood is dirty white, very light (air-dry density ca. 360 kg/m$^3$), soft and fibrous. It is liable to rot. It is a poor timber and firewood, although occasionally used as such.

**Description** Small to medium-sized deciduous tree up to 25(–35) m tall, in savanna often a shrub, shallow rooted; bole up to 60 cm in diameter, fluted; bark pale grey-brown and smooth when young, turning grey-black when ageing, and then rough and scaling at the base of the bole; slash dirty-white with scattered blotches and pits, turning greenish-brown; crown compact, with dark foliage, sometimes somewhat flattened. Leaves opposite or in whorls of 3, imparipinnate; stipules absent; petiole 7–15 cm long, rachis 15–35 cm long; leaflets (7–)9–15(–19), sessile or with up to 5 mm long petiolule, blade elliptical to ovate or ovate-oblong, (3–)7–16 cm × (1.5–)3–7 cm, asymmetrically truncate to cuneate at base




*Spathodea campanulata – 1, flowering branch; 2, dehisced fruit; 3, seed.*
*Redrawn and adapted by M.M. Spitteler.*

with 1–2 glands, acuminate or acute at apex, glabrous to pubescent below, with (6–)8–11 pairs of lateral veins. Inflorescence a terminal corymb-like raceme. Flowers bisexual, zygomorphic, large and showy; pedicel up to 6 cm long, longer in lower part of inflorescence than in upper part; calyx spathaceous, 4–8 cm long, recurved, long-acuminate, ribbed, splitting down on one side; corolla widely campanulate from a contracted base, 8–15 cm long, 5-lobed, scarlet or orange-red with yellow margin and throat; stamens 4, inserted on corolla tube, didynamous, more or less exserted, thecae divaricate; ovary superior, 2-celled, style filiform, slender, stigma 2-lamellate. Fruit a narrowly ellipsoid woody capsule 15–27 cm × 3.5–7 cm, blackish-brown, dehiscing by 2 valves, many-seeded. Seeds thin and flat, ca. 1.5 cm × 2 cm, very broadly winged.

**Other botanical information** *Spathodea* comprises only a single species, with 3 subspecies distinguished by their hairiness. Subsp. *campanulata* has glabrous leaves and ovary, a minutely velvety calyx, and is restricted to West African lowland forest. Subsp. *nilotica* (Seem.) Bidgood has densely hairy leaves and ovary, a densely velvety calyx, and is found in Central and East African lower montane forest. Subsp. *congolana* Bidgood, of the lowland forest in the Congo Basin, has leaves with scattered long curly hairs and a glabrous to curly hairy calyx and ovary. Some introgression between subspecies has been reported.

**Growth and development** Growth of the bole may be up to 5 cm/year in diameter. Flowering may start 2–3 years after planting. The flowers are individually short-lived but carried in succession over long periods. Under favourable conditions, African tulip tree may flower throughout the year. In areas with a pronounced dry season (e.g. Kenya) or cold season (e.g. southern United States, Spain) the trees are deciduous and have a marked peak in flowering. High temperatures during flowering interfere with pollen development and fertilization. The seeds are wind-dispersed. Coppice growth is reported to be excellent; trees will coppice up to at least pole size.

**Ecology** African tulip tree occurs naturally in forest fringes, riverine forest, secondary scrub, wooded savanna and open savanna, up to 2000 m altitude and in areas receiving 1300–2000 mm annual rainfall. In secondary forest, few juvenile trees are found as the species is not shade tolerant. It prefers warm, moist conditions but on deep soil it withstands drought. African tulip tree is frost tender when young. It does not produce seed at high temperatures or low relative humidity.

**Propagation and planting** Propagation is mostly by seed. Seeds do not require treatment; they are recalcitrant and their viability is short. One kg contains about 125,000 seeds.
Cuttings can also be used for propagation, larger diameter cuttings (up to 10 cm) giving the best results. Saddle and side grafting are sometimes used to multiply desirable ornamental forms, such as those with yellow flowers, with higher success rates for side grafting (75% vs. 25%). However, saddle-grafted plants have better growth. Root suckers can also be used for propagation.

**Management** The wood is soft and brittle, so planting should only take place where falling branches will not cause damage.

**Diseases and pests** African tulip tree is affected by leaf blister in Kenya and is susceptible to butt and heart rot. Fungal diseases (*Diplodia* and *Corynespora* species) attack 1–2 year old seedlings in Cuba. African tulip tree is a host of the fungus *Ceratocystis fimbriata* and *Xyleborus* beetles in Cuba, and of gypsy moth (*Lymantria dispar*) and the coreid bug *Leptoglossus zonatus*

(pest of corn, soybean, sorghum, cotton) in Brazil. Other insect pests include teak defoliator (*Hyblaea puera*) in India and a leafhopper (*Rabela tabebuiae*) in Florida.

**Genetic resources** The Subtropical Horticultural Research Unit, Miami, United States has a germplasm collection of 16 accessions. Seed is available commercially from many sources. An orange to buttercup-yellow form of the species, originally from Uganda, is popular in horticulture. It is multiplied vegetatively.

**Prospects** African tulip tree will remain important as a park and street tree, valued for its shade and spectacular flowers. Its use in agriculture and forestry and as a medicinal plant deserves more attention. It also has potential for greater use in rehabilitating disturbed lands on account of its pioneering ability and rapid growth.

**Major references** 2105, 3811, 5287, 5807, 5808, 5809, 5810, 5811, 5812, 5813

**Other references** 2054, 5814, 5815, 5816, 5817, 5818, 5819, 5820, 5821, 5822, 5823, 5824, 5825, 5826, 5827, 5828, 5829, 5830, 5831, 5832

**Sources of illustration** 5287 (dehisced fruit, seed), 5807 (flowering branch)

**Authors** C.H. Bosch

## STROPHANTHUS KOMBE Oliv.

**Protologue** Hook.f., Icon. pl. 11: 79, t. 1098 (1871).

**Family** Apocynaceae

**Chromosome number** $2n$ = unknown

**Synonyms** *Strophanthus hispidus* DC. var. *kombe* (Oliv.) Holmes (1890).

**Origin and geographic distribution** *Strophanthus kombe* occurs naturally in eastern Africa, from south-eastern Kenya and eastern Tanzania to eastern Namibia, Zimbabwe, Mozambique and northern South Africa. It is not planted on a large scale.

**Uses** The seeds and roots of *Strophanthus kombe* have been used in the preparation of arrow poison since historic times throughout the species range. Game wounded by a poisoned arrow dies quickly, while the flesh can apparently be eaten without ill effect. However, flesh immediately surrounding the wound is usually discarded.

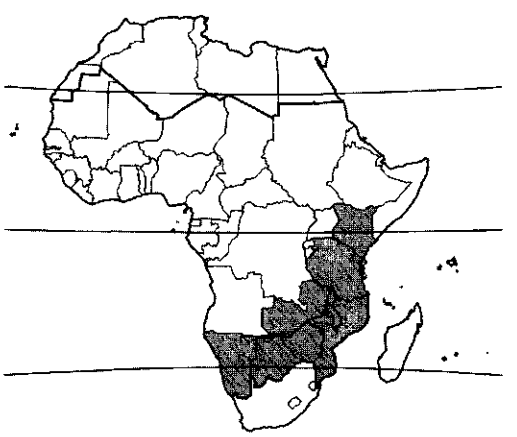
Nowadays, the glucoside strophanthin is extracted from the seeds ('Semen strophanthi') and used medicinally as a heart stimulant. It is used in a number of pharmaceuticals in several European countries for its influence on blood circulation, especially in cases of chronic heart weakness.

**Production and international trade** Although seeds of *Strophanthus kombe* are exported from Africa, mainly to Europe, there are no data on amounts and value.

**Properties** A large number of cardiac glycosides have been isolated from *Strophanthus* species. These are, in comparison with *Digitalis* cardenolides, characterized by highly oxygenated aglycones. Strophanthins, which are most abundant in the seed, are responsible for the activity as dart poison as well as cardiac and vascular stimulant activity. These compounds have been demonstrated in several *Strophanthus* species, but they were found to vary somewhat in chemical composition.

More than a dozen glycosides have been isolated from *Strophanthus kombe*, of which *k*-strophanthin is one of the most important. The cardenolide 17α-strophadogenin was also isolated from *Strophanthus kombe* seeds. A whitish, crystalline powder called strophanthinum, which is a mixture of glycosides, is prepared from the seeds. This powder is freely soluble in water, and is readily hydrolyzed into strophanthidin and a sugar when warmed with dilute acids. The seeds of *Strophanthus kombe* provide the precursor for the semi-synthetic compound acetylstrophanthidin, which is of clinical interest because of its rapid onset of action and effect when administered intravenously.

Strophanthin causes a positive inotropic effect and electrophysiological changes, possibly by inhibiting the membrane-bound $Na^+$-$K^+$-ATPase pump responsible for $Na^+$-$K^+$ exchange. It should be used with great care and under strict medical direction because of its strength. It may cause



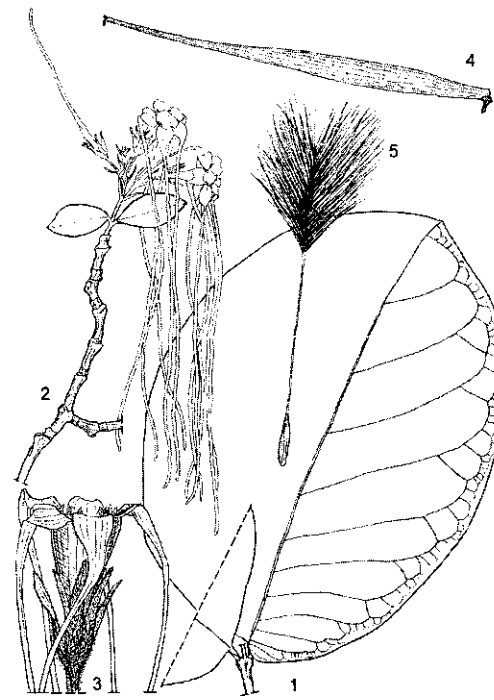
*Strophanthus kombe – wild.*

intense local irritation when administered by hypodermic injection. In urgent cases, the effects upon circulation can be obtained almost immediately by means of intravenous injection.

**Adulterations and substitutes** Cardiac glycosides are isolated from the seeds of several other *Strophanthus* species, the most important being *Strophanthus gratus* (Wall. & Hook.) Baill. and *Strophanthus hispidus* DC., both from western and central Africa. Ouabain (*g*-strophanthin) is one of these glycosides; it is commonly used to treat heart failure. It is likely that the seeds of several *Strophanthus* species are sometimes mixed before they are shipped. *Strophanthus courmontii* Sacleux ex Franch., *Strophanthus eminii* Asch. & Pax and *Strophanthus nicholsonii* Holmes, all from more or less the same region as *Strophanthus kombe*, have seeds which resemble those of the latter and are probably mixed with them in trade. The cardiac glycosides obtained from *Strophanthus* are often used as an alternative or adjuvant to those obtained from *Digitalis* species. They are often believed to have greater diuretic power, and thus to be of greater value in cases complicated with dropsy, but also more likely to cause digestive disturbances. *Drimia* species also provide cardiac glycosides used in pharmaceuticals.

**Description** Deciduous sarmentose shrub or liana up to 20 m long, with clear, white or yellow latex; roots thick and fleshy, moniliform; stem up to 10 cm in diameter; bark reddish-brown or greyish-brown; branches grooved, scabrid, sparsely to densely lenticellate, dark brown, dark grey or black, young branches densely hispid. Leaves decussately opposite, simple; stipules reduced to straight rims connecting the petiole bases; petiole 1.5–5 mm long, with 6–14 colleters; blade ovate or elliptical, less often obovate to orbicular, 8–24 cm × 5–17 cm, cuneate, rounded or subcordate at base, obtuse, acute or acuminate at apex, margin entire, papyraceous to chartaceous, densely hispid when young but glabrescent above, pinnately veined with 7–13 pairs of secondary veins, tertiary venation conspicuous beneath. Inflorescence a terminal dichasial cyme, on short branches or in forks of larger branches, rather congested, densely hispid, pedunculate, 1–12-flowered; bracts narrowly ovate to linear, up to 23 mm long. Flowers bisexual, regular, 5-merous, fragrant; pedicel up to 20 mm long; sepals free, subequal, narrowly ovate to linear, 9–27 mm × 1.5–3.5 mm, acute, hispid; corolla white turning yellow, pinkish to purplish-spotted, with hispidulous tube 13–24 mm long, widening about halfway into a cup-shaped upper part, ovate lobes 3–16 mm × 4–8.5 mm, narrowing into c. 1 mm wide pendulous tails 90–190 mm long, and lingulate corona lobes 1–3 mm × 1–2.5 mm; stamens inserted at about halfway the corolla tube, included in the upper part of the tube, filaments shorter than 4–6 mm long anthers connivent in a closed cone around the clavuncle and stigma; ovary hemi-inferior, hispid, 2-celled, abruptly narrowing into 6–14 mm long style ending in a clavuncle surrounding the central stigma. Fruit consisting of 2 narrowly ovoid to fusiform follicles 15–47 cm × 1.5–2.5 cm, divergent at 180°, long tapering and ending in a small knob, woody, hispid or pubescent but glabrescent, densely lenticellate, many-seeded. Seeds almost fusiform, slightly flattened, 11–21 mm × 1.5–4.5 mm, pubescent, at apex with a glabrous beak 20–57 mm long and topped by a coma of many hairs 42–80 mm long. Seedling with epigeal germination; primary root sometimes swollen; cotyledons elliptical or ovate, obtuse at apex, glabrous; first leaves resembling leaves of mature plants but usually narrower.

**Other botanical information** *Strophanthus* comprises 38 species: 30 in Africa, 1 in Madagas-




*Strophanthus kombe – 1, mature leaf; 2, flowering branch; 3, flower; 4, fruit, one follicle removed; 5, seed.*
*Redrawn and adapted by M.M. Spitteler.*

car and 7 in Asia. Many of these species are used medicinally. *Strophanthus kombe* is closely related to *Strophanthus hispidus* from western and central Africa, but can be distinguished by its narrower outer sepals that are about as wide as the inner (much wider than the inner in *Strophanthus hispidus*) and follicles divergent at 180° (200–260° in *Strophanthus hispidus*).

**Growth and development** Flowering of *Strophanthus kombe* occurs towards the end of the dry season and the beginning of the rainy season. Nothing is known about pollinators, although flower structure and colouring suggest butterflies. Fruits mature in the dry season. Seeds are dispersed by wind.

**Ecology** *Strophanthus kombe* occurs in coastal forest, gallery forest, riparian thickets and woodland, often on inselbergs, up to 1100 m altitude.

**Propagation and planting** At the Royal Botanic Gardens, Kew, United Kingdom, semi-ripe cuttings are taken in April. Cuttings are dipped into a rooting hormone and then placed in pots containing a coir and perlite mix, in a mist unit at a temperature of 25°C and relative humidity of 80%. When rooted, after about 4 weeks, they are potted up.

***In vitro* production of active compounds** Although callus induction has yet to be established for *Strophanthus kombe*, cell suspension cultures have been prepared successfully from plant segments of some other *Strophanthus* species. The biotransformation of digitoxigenin (which was added to the cell suspension cultures) to various products was observed in these cultures, but cardenolide production could not be demonstrated. However, the production of cardenolides was observed in *Strophanthus divaricatus* (Lour.) Hook. & Arn. plants from Asia, regenerated from callus.

**Management** Seeds intended for trade are usually collected from wild plants. As far as is known, *Strophanthus kombe* is not cultivated on a large scale.

**Handling after harvest** In preparing the arrow poison, the seeds are pounded to a pulp after removal of the coma. An adhesive is added (e.g. *Euphorbia* latex or saliva), the mixture is sometimes exposed to strong sunlight for some hours, and subsequently smeared along the point of the arrow.

*Strophanthus* seeds should be preserved in tightly-closed containers, and a few drops of chloroform or carbon tetrachloride should be added from time to time to prevent insect attacks. The drug is extracted with absolute alcohol, the oil is removed from the percolate with petroleum ether, and the glucosides are subsequently converted into strophanthidin by boiling with hydrochloric acid.

**Genetic resources** There are no indications that *Strophanthus kombe* is at risk of genetic erosion. Large germplasm collections of *Strophanthus* do not exist. The glycoside concentration differs per population. Variability studies are needed to evaluate this.

**Prospects** *Strophanthus* is a source of compounds that are useful in treating heart failure and blood circulation disorders. The biotransformation abilities of *Strophanthus* plant cell and tissue cultures may provide new, more effective and safer cardiac glycosides useful in the pharmaceutical industry.

**Major references** 5504, 5505, 5506, 5507
**Other references** 3815, 5509
**Sources of illustration** 5504
**Authors** H.J. Beentje

## TIEGHEMELLA HECKELII (A.Chev.) Roberty

**Protologue** Petite Flore de l'ouest-Africain: 79 (1954).

**Family** Sapotaceae

$2n = 24$

**Synonyms** *Dumoria heckelii* A.Chev. (1907), *Mimusops heckelii* (A.Chev.) Hutch. & Dalziel (1931), *Baillonella heckelii* (A.Chev.) Baehni (1965).

**Vernacular names** Makore (En). Makoré (Fr).

**Origin and geographic distribution** *Tieghemella heckelii* occurs in the West African

*Tieghemella heckelii – wild.*

forest zone, from Sierra Leone eastwards to southern Nigeria, but not in Togo or Benin.

**Uses** The wood, traded as makore or cherry mahogany, is used for furniture, interior construction, flooring, doors, vehicle frames, sports goods, railway sleepers, turnery and sculptures, and makes good and decorative veneer, often used to face plywood.

The seed kernels (cotyledons, known as 'baco') are rich in an edible fat known as 'dumori butter' or 'makore butter', which is locally popular as a cooking or seasoning oil and often preferred to palm oil. The fat is also applied as a pomade to the body and hair, and used in soap production. The fleshy and very sticky pulp of the fruits is sometimes used as birdlime. The bark is reportedly effective for treating blennorrhoea and toothache and, in Liberia, young buds are used to treat snake bites.

**Production and international trade** Makore is traded on the international timber market, but production is small due to limited supply from natural stands. The export of makore timber from Côte d'Ivoire declined from 70,000 $m^3$ in 1960 to 28,000 $m^3$ at the beginning of the 1980s and 6000 $m^3$ at the end of the 1980s.

**Properties** Makore is a medium-weight wood. It resembles African mahogany (*Khaya* species), but the texture is finer. The heartwood is pinkish-, purplish- or reddish-brown with a silky lustre, often with a decorative figure in the form of flames or stripes. The sapwood is up to 8 cm wide and yellowish-grey to greyish-brown. The density is 600–800 kg/$m^3$ at 12% moisture content. The grain is straight or interlocked, texture fine and even.

In a test of wood with a density of 609 kg/$m^3$ at 12% moisture content, the modulus of rupture was 96 N/$mm^2$, modulus of elasticity 10,800 N/$mm^2$, compression parallel to grain 51 N/$mm^2$, shear 12.6 N/$mm^2$, cleavage 71 N/mm radial and 76 N/mm tangential, and Janka side hardness 4940 N.

The shrinkage rates of makore are low to moderate. In a test, shrinkage of the wood from 90% to 60% air moisture content was 1.1% radial and 1.8% tangential. Shrinkage from green to 12% moisture content was 3.0% radial and 4.5% tangential, and from green to oven dry 6.0% radial and 7.7% tangential. Usually, drying does not cause problems, although the wood dries slowly.

The wood is somewhat difficult to work due to the presence of silica; blunting effects are moderately severe when sawing. The wood finishes well. Staining and polishing give good results. Preboring for nailing and screwing is recommended to avoid splitting. Gluing properties are good. The timber can be peeled satisfactorily.

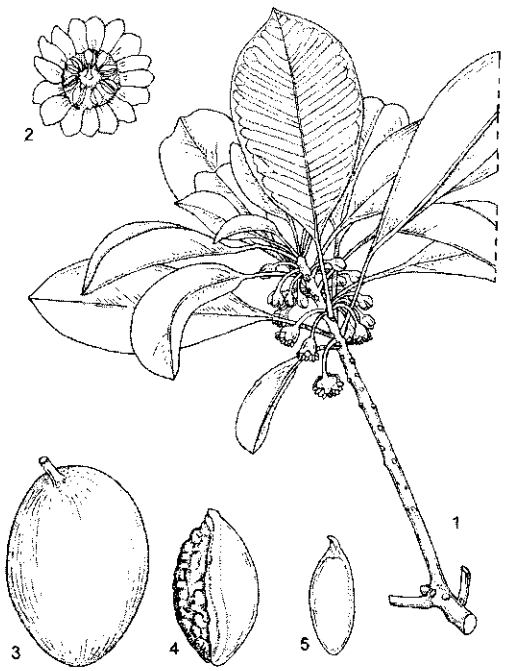
The heartwood is rated as one of the most durable African timbers. It is resistant to termites and fungi. Damage by pinhole borers and powder-post beetles has been recorded occasionally. Although it is resistant to marine borers in temperate waters, the wood is not very durable in tropical (especially brackish) waters. The heartwood is very difficult to impregnate, the sapwood moderately easy.

Dust from sawn wood may cause irritation to skin and mucous membranes. It has been suggested that this is caused by the presence of saponins or the contact allergen 2,6-dimethoxy-1,4-benzoquinone. A highly haemolytic saponin has been isolated from the wood; on hydrolysis it gave d-glucose, l-rhamnose and d-xylose.

The fruit is sticky, juicy, has an unpleasant smell and bitter taste. The fatty oil from the seed kernel is yellowish and semi-fluid, has no distinct flavour or taste, and consists of about 51% oleic acid, 43% stearic acid, 3.5% palmitic acid and 2.5% linoleic acid. The kernel comprises about 60% of this oil by weight.

**Adulterations and substitutes** Makore is used for similar purposes as African mahogany (*Khaya* species), but it is more durable. It is sometimes even traded as African mahogany. It is very similar to the wood of the only other species of the genus, *Tieghemella africana* Pierre from Central Africa, which is often also traded as makore or 'douka'.

**Description** Very large tree up to 55 m tall; bole up to 250 cm in diameter, straight and cylindrical, often swollen in lower part, reaching up to 30 m to the first branches, angular or ridged at base, or with large, narrow buttresses up to 3 m high and heavy, spreading surface roots; bark surface grey to nearly black, deeply furrowed with rectangular scales, inner bark fibrous but brittle, exuding a sticky latex; crown heavy, rounded, heavy branches often abruptly spreading. Leaves arranged spirally, more or less in tufts, simple; stipules absent; petiole 1.5–4 cm long, slender; blade elliptical to obovate, 6–15 cm × 2–6.5 cm, cuneate at base, emarginate, rounded, acute or acuminate at apex, margin entire to slightly undulate, papery or thinly leathery, glabrous, lateral veins numerous. Flowers in fascicles of 1–4 (as a rule 2) in the leaf axils, bisexual, regular; pedicel 1.5–2.5 cm long; calyx with 2 whorls of 4 lobes 3–5 mm long, softly tomentellous on the




*Tieghemella heckelii – 1, flowering twig; 2, flower; 3, fruit; 4, seed; 5, seed kernel.*
*Redrawn and adapted by W. Wessel-Brand.*

overlapped parts; corolla with 2–2.5 mm long, fleshy tube and 8 lobes, each lobe with 1 minute median segment and 2 large, fleshy, imbricate lateral segments 3–3.5 mm long, creamy white; stamens 8, inserted on the corolla tube in front of the corolla lobes, free, filaments short, 8 short staminodes alternating with the stamens; ovary superior, conical, softly tomentellous, 8-celled, each cell with 1 ovule, style short. Fruit a large, ovoid-subglobose, smooth berry 8–12 cm long, yellow when ripe, containing 1–3 seeds in a yellowish pulp. Seeds broadly ellipsoid, slightly laterally compressed, (5–)6–7.5 cm long, testa thick, woody, smooth, shining and yellowish-brown in dorsal part, rough and bullate in ventral part (scar); endosperm absent. Seedling with epigeal germination, hypocotyl stout, up to 14 cm long, epicotyl up to 11 cm long, cotyledons thick, sessile, ca. 5 cm × 2 cm, dark green.

**Other botanical information** The genus *Tieghemella* consists of 2 species and is closely related to *Mimusops*, differing in having less-developed corolla tubes, smaller fruits, and seeds with smaller scars, copious endosperm and thin cotyledons. *Tieghemella africana* occurs in Cameroon and Gabon. It resembles *Tieghemella heckelii* and may be conspecific. A taxonomic study is needed to clarify the species limits and the status of the genus, which is complicated by the fact that the name *Tieghemella* was first published for a genus of fungi.

**Anatomy** Wood-anatomical description:
– Macroscopic characters:
Heartwood pinkish-, purplish- or reddish-brown, very distinctly demarcated from the usually wide, yellowish-grey to greyish-brown sapwood. Grain straight or interlocked. Texture fine. Growth rings absent or indistinct.
– Microscopic characters:
Vessels diffuse, 5–30/mm², generally in radial multiples of 3–6(–15), occasionally solitary or in pairs, often oblique, oval, 70–220 µm in tangential diameter; perforations simple; intervessel pits alternate, comparatively large; tyloses present. Fibres 1000–1650 µm long, non-septate, with few scattered simple pits on tangential walls. Parenchyma reticulate, apotracheally banded. Rays 4–15/mm, mainly multiseriate, generally 3 cells wide and 8–18 cells high, but 2-seriate cells also present, up to 1.5 mm high and 15–70 µm broad, heterogeneous. Crystals absent. Axial parenchyma cells with gummy deposits.

**Growth and development** Initial growth of seedlings is fast, up to 70 cm in 4 months, but then often ceases while a strong taproot is formed. Growth of young *Tieghemella heckelii* trees is reported as slow, but strongly depends on light. Under conditions above 20% of full light, growth may be up to 1 m/year; under 10% growth is almost nil. Other reports indicate, however, that maximum growth is reached at an irradiance of 10% of unshaded values. In Ghana, young trees have been reported to be 1–2 m tall after 1–1.5 years in a nursery, and when planted under shade trees in the field 1.5–3.5 m tall after 13 years. However, in western Côte d'Ivoire, trees have been reported to be 3 m tall after 4 years and 9–11 m tall after 20 years with a stem diameter of 13–16 cm, occasionally even 28 m tall after 21 years with a diameter of 37 cm.
Trees develop according to Aubréville's model: the monopodial trunk shows rhythmic growth, with whorled branches, which also grow rhythmically but modularly, each branch plagiotropic by apposition, the modules growing indefinitely.
Trees start flowering and fruiting after about 17 years, but sometimes after 10 years. Flowers open in the early morning, the corolla being shed in the afternoon of the same day. In Liberia, flowering is from February to May; ripe fruits can be found between October and December. In Côte d'Ivoire,

flowering occurs from January to June, and ripe fruits can be found from August to March. A tree produces approximately 3000–4000 fruits at a time. The fruits are eaten by elephants, which are probably the main seed dispersers; bush-pigs are also reported to feed on the fruits.

**Ecology** *Tieghemella heckelii* is often an emergent tree of the high forest. It is found in moist evergreen and semi-deciduous forests. Regeneration in these forests is reportedly reasonable, at least in Ghana; there is a strong preference for undisturbed forest. Young trees are very tolerant of shade, but can survive in full sun. Heavy soils are preferred.

**Propagation and planting** *Tieghemella heckelii* is easy to propagate. The seeds are heavy, 30–50 seeds/kg. Viability decreases rapidly. They should be planted within 2 weeks. In the nursery, seeds are usually planted at a spacing of 40 cm × 40 cm under light shade. Seedbeds should be watered well. Germination is over 90% in optimal conditions, and without pre-treatment. It begins after about 4 weeks, most seeds having germinated after 10 weeks, but it may continue for 16 weeks. Rodents may cause considerable damage to seeds and seedlings (cotyledons). Saplings of about 2.5 years old and 1–1.5 m tall are planted out into the field used at the beginning of the rainy season, but in western Côte d'Ivoire 0.5 year-old seedlings are used.

Propagation by air layering and cuttings is successful. In a test with air layering, 39% of branches rooted and 56% had developed callus after 8 weeks. The average rate of rooting of branch cuttings after 6 months was 73%. In neither case did the application of indole-butyric acid improve rooting success.

**Management** The density of *Tieghemella heckelii* in the forest is generally low. Reports for Côte d'Ivoire vary from 1 exploitable tree per 23 ha to 1.4 trees above 10 cm diameter per ha. The average of 9 inventories in Côte d'Ivoire was 4.1 $m^3$ of timber per 100 ha for trees exceeding 70 cm diameter. The average of 16 inventories in Liberia was 33 $m^3$ of timber per 100 ha for trees exceeding 40 cm diameter. Experiments in Côte d'Ivoire showed that thinning of the forest leads to better recruitment and growth.

*Tieghemella heckelii* has been planted on a small scale (almost 6 ha), mainly for seed oil production, in western Côte d'Ivoire (near Taï National Park) with an average density of 357 stems/ha. It is often planted at a density of about 120 trees/ha, in association with coffee, cocoa, rubber or rice, and at field margins and in secondary forest following clearance of undergrowth.

**Diseases and pests** No information on diseases and pests is available, although *Tieghemella heckelii* is a host of the semi-parasitic tree *Okoubaka aubrevillei* Pellegr. & Normand.

**Harvesting** Logs tend to split badly during felling. Logs of larger trees are often hollow.

**Yield** Fat yield is 20–30 kg/tree per harvest. One kg of seed kernels yields about 200 g of fat when the traditional method of extraction is used.

**Handling after harvest** The seeds are split, and the kernels dried in the sun, roasted, pounded to a paste and boiled in water. The fat or oil is skimmed off from the water.

**Genetic resources** *Tieghemella heckelii* is reported to be rather rare in Liberia. The density in Côte d'Ivoire is low, and in many areas *Tieghemella heckelii* is considered rare. In Ghana, it is fairly common, but under pressure as a result of forest exploitation, and deserves protection. The seeds are probably dispersed by elephants, which are becoming rare in West Africa and therefore limiting natural regeneration.

**Prospects** The prospects for planting programmes in West Africa using *Tieghemella heckelii* are good. Seed and vegetative propagation is easy. The species can be planted in open sites, grows fairly rapidly, and has a fairly open crown structure which permits good light penetration, making it suitable for use in agroforestry programmes. The wood, and fat from the seeds, are of excellent quality. However, planting for fat production may be uneconomic as it takes a rather long time for trees to fruit after planting, and fat yields are limited. Planting is needed to take pressure off wild populations.

**Major references** 2108, 3821, 5536, 5537, 5538, 5539

**Other references** 4410, 5540, 5541, 5542, 5543, 5544

**Sources of illustration** 5539

**Authors** L. Bonnéhin & R.H.M.J. Lemmens

## VIGNA SUBTERRANEA (L.) Verdc.

**Protologue** Kew Bull. 35(3): 474 (1980).

**Family** Papilionaceae (Leguminosae - Papilionoideae, Fabaceae)

**Chromosome number** $2n = 22$

**Synonyms** *Glycine subterranea* L. (1763), *Voandzeia subterranea* (L.) DC. (1825).

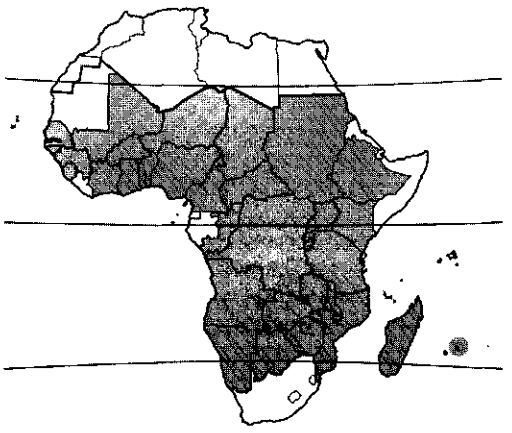
**Vernacular names** Bambara groundnut, bambarra groundnut, earth pea (En). Voandzou, pois de terre, pois bambara (Fr). Mancara de

Bijagó, jinguba de Cabambe (Po). Njugu mawe (Sw).

**Origin and geographic distribution** The centre of origin of bambara groundnut is probably north-eastern Nigeria and northern Cameroon. It is found in the wild from northern Nigeria to Cameroon and perhaps the Central African Republic, and is now cultivated throughout tropical Africa, and to a lesser extent in America, Asia and Australia. Its use as a pulse in West Africa was recorded by Arabic travellers in the 14th Century. Its importance has declined following the introduction of groundnut from the New World tropics.

**Uses** Bambara groundnut is grown primarily for its seeds, which are used in many types of foods, some of which, apart from being an important part of the diet, play a role in traditional ceremonies and in gift exchanges. Mature, dry seeds are boiled and eaten as a pulse. Dried seeds, either whole or split, are also mixed with maize or plantains and then boiled. The seeds may be ground into flour, sometimes after roasting, to prepare a porridge. They can also be added to maize flour to enrich traditional preparations. Sometimes seeds are pre-soaked and ground into a paste which is used to prepare fried or steamed dishes. Fresh immature seeds are often boiled with salt and eaten as a snack. The immature seeds can fill the 'hungry gap' during the growing season, when stores are empty and crops are not yet ready for harvest. Vegetable milk and fermented products similar to tempe (from *Glycine max* L.) and dawadawa (*Parkia biglobosa* (Jacq.) R.Br. ex G.Don) are obtained from the seeds. Leafy shoots are used as fodder. In Senegal, leaf preparations are used to treat abscesses and infected wounds, leaf sap is applied to the eyes to treat epilepsy, and the roots are sometimes taken as an aphrodisiac. Pounded seeds mixed with water are administered to treat cataract. The Igbo in Nigeria use the plant against venereal diseases.

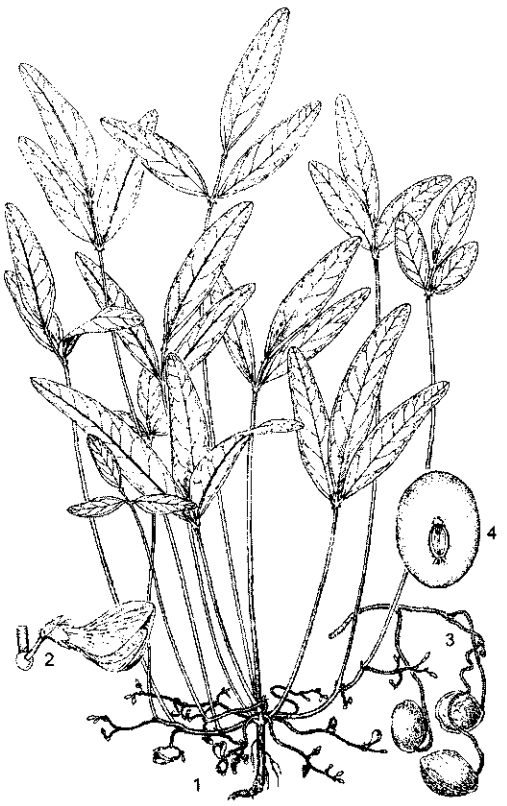
**Production and international trade** Reliable production figures are difficult to obtain, because the crop is mainly grown for home consumption and sale at local markets. In the early 1980s the annual world production was estimated at around 330,000 t, 45–50% of which was produced in West Africa. The major producers are Burkina Faso, Chad, Côte d'Ivoire, Ghana, Mali, Niger and Nigeria, but the crop is also widely grown in eastern and southern Africa and in Madagascar. The main exporting countries are Burkina Faso, Chad, Mali, Niger and Senegal; they supply markets in Benin, Ghana, Nigeria and Togo.



*Vigna subterranea – wild and planted.*

**Properties** Per 100 g edible portion bambara groundnut seeds contain: water 10 g, protein 18 g, fat 6 g, carbohydrates 60 g, fibre 3 g, calcium 65 mg, iron 6.0 mg, thiamine 0.3 mg, riboflavin 0.1 mg and niacin 2.0 mg. The energy content averages 1540 kJ/100 g. As in other leguminous seeds, the sulphur-containing amino acids cystine and methionine are limiting. The main fatty acids in oil extracted from seeds are linoleic acid 34–40%, palmitic acid 18–24%, oleic acid 18–24%, stearic acid 5–12%, behenic acid 3–7% and linolenic acid 2–3%. A content of 21% linolenic acid and no oleic acid, however, has also been reported. The ratio of saturated to unsaturated fatty acids is approximately 1:2. The oil content is too low for use as an oilseed. Trypsin inhibition occurs. The seeds contain tannins, mainly in the seed coat. Higher levels of tannins are found in genotypes with black (0.67–0.86%) and red (0.10–0.43%) seeds than in those with cream-coloured seeds (0.05%). The concentration of antinutritional factors is reduced by cooking and other forms of processing. Cream-coloured seeds are often eaten in preference to the more bitter tasting red and black seeds. Ripe seeds are very hard and usually have to be cooked longer than those of other legumes. Dried leaves for fodder contain 15.9% crude protein, 31.7% crude fibre, 7.5% ash and 1.8% fat.

**Description** Annual herb with creeping stems branching just above ground level; root system consisting of a tap root with lateral roots lower down, nodules rounded and sometimes lobed. Leaves trifoliolate, glabrous; stipules ca. 3 mm long, spurred, striate; petiole erect, grooved, up to 30 cm long, thickened at base; rachis (0.1–)1–




*Vigna subterranea – 1, habit of flowering plant; 2, flower; 3, fruits; 4, seed.*
*Source: PROSEA.*

2.5 cm long; leaflets with ovate-oblong stipels up to 3 mm long, petiolule 1–3 mm long, blade elliptical to oblanceolate, up to 10 cm × 4 cm. Inflorescence an axillary, (1–)2(–3)-flowered raceme, close to the ground; peduncle 0.5–2 cm long. Flowers bisexual, papilionaceous, shortly pedicelled; calyx with tube ca. 1 mm long and 5 lobes ca. 1 mm long; corolla whitish-yellow, standard obovate, 4–7 mm long, wings and keel slightly shorter; stamens 10, 9 with filaments fused for more than half their length and 1 free; ovary superior, 1-celled, style bent. Fruit a subspherical indehiscent pod ca. 2.5 cm in diameter, usually 1-seeded. Seed 8.5–15 mm × 6.5–10 mm, variously coloured from white to cream, red, black or brown, sometimes mottled, blotched or striped; eye around the hilum sometimes present, colour and shape variable. Seedling with hypogeal germination.

**Other botanical information** There is considerable morphological difference between domesticated and wild bambara groundnut resulting from selection. Wild bambara groundnut produces long internodes, the pods are thin and do not wrinkle upon drying, and the seeds are small (9–11 mm long) and quite uniform in size. Domesticated forms are more compact, with the petioles longer, less slender and more erect, fleshy pods which wrinkle on drying, and larger seeds (11–15 mm long). Morphological and isozyme data indicate a gradation from wild to domesticated bambara groundnut through weedy populations. Wild and domesticated forms are sometimes distinguished as var. *spontanea* (Harms) Hepper (wild), and var. *subterranea* (cultivated). No cultivars of bambara groundnut have been named, but genotypes are distinguished on the basis of seed attributes (colour, size, hardness) and plant form (bushy or spreading).

**Growth and development** Germination rates increase linearly with temperature increase from 17–32°C, and decline with temperature increase from 32–40°C. Below 17°C and above 40°C, germination is very poor. Emergence takes 5–15 days. Flowering starts 30–55 days after sowing and may continue until the plant dies. Self-pollination is the rule. After fertilization, the peduncle grows and pods form on or below the ground. Pods reach their maximum size in about 30 days. The seeds expand during the following 10 days. Seeds are mature 3–6 months after germination, when the parenchymatous layer surrounding the embryo has disappeared and brown patches appear on the outside of the pod. Bambara groundnut nodulates freely with rhizobial bacteria of the *Bradyrhizobium* group.

**Ecology** Bambara groundnut is cultivated in the tropics at altitudes up to 1600 m. A frost-free period of at least 3 months is necessary. Average day temperatures of 20–28°C and full sun are preferred. The crop can tolerate drought and is cultivated successfully in areas with a rainfall of 600–750 mm/year, though optimum yields are obtained when rainfall is higher (900–1200 mm/year). It is also grown in humid conditions, e.g. in northern Sierra Leone, where the annual rainfall exceeds 2000 mm. There are large differences between genotypes in their response to temperature and photoperiod. In many genotypes, flowering is photoperiod-insensitive, while the onset of podding is retarded by long photoperiods. In some genotypes, however, both flowering and the onset of podding are delayed by long photoperiods. Podding may also be delayed by drought.

The plant grows on any well-drained soil, but light sandy loams with a pH of 5.0–6.5 are most

suitable. Soils rich in phosphorus and potassium are suitable, but calcareous soils are not. Nitrogen-rich soils promote vegetative growth at the expense of seeds.

**Propagation and planting** Bambara groundnut is propagated by seed. The seeds are orthodox and can be stored below 0°C. The 1000-seed weight is 500–750 g; sowing rates range from 25–160 kg/ha. Most farmers do not buy seed, but use seed retained from the previous harvest. Farmers usually select the seeds to be retained as planting material after harvesting. Seeds are stored in bags, bottles, gourds or calabashes sometimes sealed with mud. Seeds should be shelled just before sowing to maximize viability, but otherwise are not usually pretreated.

Bambara groundnut is not usually sown immediately after the first rains, because staple food and cash crops tend to receive priority. Sowing dates vary considerably within locations. In Zambia and Botswana, for example, sowing takes place from November to February. Late sowing, however, may result in large yield reductions. Sometimes phased planting occurs, e.g. in Sukumaland, Tanzania. Land is cleared, and may be ploughed and ridged before sowing. In Botswana, fields are sometimes ploughed after the seed has been broadcast. The crop performs best on deeply ploughed fields with a fine seed-bed, eventually allowing the plant to bury its peduncles. Ridging is advisable if the soil is shallow or susceptible to waterlogging. When sowing a new field, inoculation with soil from an old bambara groundnut field is recommended to promote nodulation with rhizobial bacteria.

Bambara groundnut is sown in rows or broadcast; densities range from 2,500 plants/ha (mixed cropping in Botswana) to 250,000 plants/ha (sole cropping in Nigeria). Rows can be 20–40 cm apart (in Nigeria) to 50–100(–400) cm apart (in Botswana). Spacings can be 20–40 cm within rows (in Nigeria) to 10–100 cm (in Botswana). Dry matter production of bambara groundnut is low, so high plant densities are recommended. However, high densities are only possible where rainfall and soil fertility are adequate. Sowing is often performed by making a hole with hoe, hand or foot, dropping 1–4 seeds in the hole and covering with soil. Use is sometimes made of an animal- or tractor-pulled planter, or the seed may be sown immediately behind a plough. Under rainfed conditions in sandy soils a sowing depth of at least 6 cm is advisable. Thinning may be practised, often in combination with weeding. When establishment problems occur, gaps are sometimes infilled with seeds of bambara groundnut or other crops.

Bambara groundnut may be the sole crop or can be mixed with cereals, other pulses, root and tuber crops, or vegetables. It is often grown together with maize, sorghum, pearl millet, groundnut and cowpea. It is used in rotations with maize, sorghum, pearl millet, cassava, yam, groundnut, cowpea and bean because it has a residual nitrogen effect. Bambara groundnut is mainly grown by smallholders, often women, usually on very small fields (seldom more than 0.5 ha). Where both men and women are involved in bambara groundnut cultivation, e.g. in Zambia and Botswana, the former are usually involved in clearing and tilling the soil, and the latter in sowing, weeding and harvesting.

**Management** Weeding takes place 1–3 times, often with a hoe. Earthing up by hand, or with a hoe, to cover the peduncles is common. This improves yields and is often combined with weeding. Nitrogen needs may be met by symbiotic nitrogen fixation. A nitrogen fixation rate of about 100 kg/ha has been reported, but sufficient phosphorus availability is essential for nodulation. The use of fertilizers is not common, but sometimes animal manure or chemical fertilizers are applied. Responses to applied nitrogen and phosphorus in field experiments have varied. Research in Botswana has shown that under the prevailing conditions nitrogen fertilization is not advisable, whereas phosphorus application is only beneficial when it is applied close to the seedlings within 2 weeks of sowing and when the soil during this period is kept moist.

**Diseases and pests** Although considered to be less affected by pests and diseases than groundnut and cowpea (perhaps due to it being grown on a smaller scale and having a wider genetic diversity) several diseases and pests can cause serious damage to bambara groundnut. The most important fungal pathogens are *Cercospora* species, *Erysiphe polygoni* and *Fusarium oxysporum*. Symptoms of *Cercospora* leaf spot are reddish-brown circular spots on the leaves, as well as lesions on the stems, petioles, peduncles and pods. The lesions may coalesce to give the appearance of blight. In cases of severe attack, defoliation occurs and plants may die prematurely. Crop rotation and burning of crop debris of the previous season are recommended to reduce damage, but the best solution is to use resistant genotypes. Symptoms of mildew (*Erysiphe polygoni*) are a whitish powder on both sides of the leaves, especially on the upper surface. Infected leaves dry out and die. Treatment with the fungi-

cide chlorothalonil has sometimes been effective. *Fusarium oxysporum* causes vascular discolouration, yellowing, necrosis and wilting and plants become stunted and eventually die. Crop rotation may help, but planting more resistant genotypes seems the best control. Other fungal diseases affecting bambara groundnut include leaf spot caused by *Phyllosticta voandzeia*, leaf blotch due to *Phomopsis* sp. and seedling blight and pod and stem rot caused by *Sclerotium rolfsii*. Virus diseases include cowpea mottle virus, cowpea aphid-borne mosaic virus and peanut mottle virus. Genotypes resistant to cowpea mottle virus have been identified. Root-knot nematodes (*Meloidogyne incognita, Meloidogyne javanica*) can seriously affect yields.

Pests of germinating seeds include rats, termites, ants and cutworms (*Agrotis*). Leaves may be attacked by insect pests such as aphids, grasshoppers, leaf hoppers such as *Empoasca facialis*, *Hilda patruellis*, the beetle *Ootheca mutabilis*, and the moths *Diacrisia maculosa* and *Hedylepta indicata* (*Lamprosema indicata*). One of the most serious pests in Swaziland is the American bollworm (*Helicoverpa armigera*). Leaves may also be eaten by mammals, such as duikers (*Sylvicapra grimmia*). Maturing seeds may be attacked by rats, ants, wild pigs, monkeys and bushbabies (*Galago* species). Important storage pests are the bruchid beetles *Callosobruchus maculatus* and *Callosobruchus subinnotatus*, and the maize weevil *Sitophilus zeamais*. Infestation often begins in seeds ripening in the field and is later carried into the stores. Stored seeds are sometimes protected by applying ash, chemical products (malathion, carbamyl) or plant products (e.g. ground tobacco leaves, ground peppers or the leaves of basil (*Ocimum basilicum* L.).

The parasitic plant *Alectra vogelii* Benth. may reduce yields considerably, e.g. in Swaziland yields may be halved.

**Harvesting** Bambara groundnut is harvested 90–180 days after sowing, depending on genotype, ecological conditions and farmers' objectives. As the seeds may be consumed either unripe or ripe, different harvesting methods exist. Unripe seeds may be harvested in several rounds from the same plants. Mature seeds are harvested when the leaves turn yellow and fall, and when the pods have become hard. In the latter case, harvesting is usually done by uprooting the plants by hand or with a hoe. Since pods break off easily, gleaning is useful. The leaves are left in the field or fed to animals.

**Yield** Yield fluctuations between years are large and mainly depend on rainfall. The highest recorded seed yield under field conditions is close to 4000 kg/ha. Average yields are 300–800 kg/ha, but yields of less than 100 kg/ha are not uncommon. Bambara groundnut still gives some yield under conditions (poor soils, drought) which are too marginal for groundnut and other pulses.

**Handling after harvest** The pods are dried in the sun to a moisture content of about 12% and stored in bags or drums in granaries or in the house. They may be shelled first with mortar and pestle, flails or modified groundnut shellers. The shelling percentage ranges from 70–77% by pod weight. Seeds stored in the shell suffer less from deterioration and infestation by insects than shelled seeds. Bambara groundnut is a typical dual purpose crop: usually part of the harvest is sold and part is kept for own consumption. Canning of bambara groundnut seeds has been done in Ghana and Zimbabwe.

**Genetic resources** The largest germplasm collection (about 2000 accessions from sub-Saharan Africa) is held by IITA (International Institute of Tropical Agriculture) in Nigeria. About 1400 accessions in this collection have been sown in the field and subsequently characterized, evaluated and documented. Other large collections are present at the IRD (Institut de Recherche pour le Développement, formerly ORSTOM) in France (about 1200 cultivated and 60 wild accessions from Cameroon, of which 50 morphologically characterized), the University of Zambia (460 accessions), the Grain Crops Institute in South Africa (200 accessions) and the Plant Genetic Resources Centre in Ghana (170 accessions). In many African countries smaller collections are maintained.

**Breeding** Selection has been made between and within bambara groundnut populations for yield, disease resistance (to *Fusarium* wilt and *Cercospora* leaf spot) and drought tolerance. Genotypes in the IITA germplasm collection have been identified with a longer and denser root system. These may be useful in selection and breeding programmes for drought tolerance. Breeding of genotypes with a shorter growth period seems also useful for drier regions such as northern Nigeria. Selection of the most effective combinations of genotypes and rhizobial strains seems promising to increase nitrogen fixation and crop yields.

**Prospects** Bambara groundnut is a suitable crop for semi-arid regions, because it tolerates drought and poor soils better than such crops as cowpea and groundnut, and also appears to be

less affected by diseases and pests than those crops. Farmers also value its multiple uses and good taste. Although bambara groundnut will remain an important secondary food crop in Africa, the area under cultivation will probably not increase much, because of high labour requirements, especially for earthing up and harvesting, the absence of an export market outside Africa, and the competition from groundnut and cowpea. The prospects of bambara groundnut as a food crop can be improved by developing high-yielding genotypes with improved disease resistance and lower anti-nutritional factors, such as tannins. The development of new food product composites with cereals may also lead to increased use of the crop.

**Major references** 5844, 5845, 5846, 5847, 5848, 5849, 5850, 5851, 5852, 5853

**Other references** 2017, 2107, 4002, 5854, 5855, 5856, 5857, 5858, 5859, 5860, 5861, 5862, 5863, 5864, 5865, 5866, 5867, 5868, 5869, 5870

**Sources of illustration** 3783

**Authors** M. Brink, G.M. Ramolemana & K.P. Sibuga

## VITELLARIA PARADOXA C.F.Gaertn.

**Protologue** Suppl. carp.: 131, t. 205 (1807).

**Family** Sapotaceae

**Chromosome number** $2n = 24$

**Synonyms** *Butyrospermum niloticum* Kotschy (1865), *Butyrospermum parkii* (G.Don) Kotschy (1865), *Butyrospermum paradoxum* (C.F. Gaertn.) Hepper (1962).

**Vernacular names** Shea butter tree, shea tree, bambouk butter tree, galam butter tree (En). Karité, arbre à beurre (Fr).

**Origin and geographic distribution** *Vitellaria paradoxa* is indigenous to the Guinea and Sudan savanna zone from Senegal in the west to Sudan and Ethiopia in the east, in a belt 500–700 km wide and 5000 km long. It is found in the interior, separated from the Gulf of Guinea by forest; only in Ghana and Nigeria does it occur within 50 km from the coast. In eastern Africa, it is found more than 750 km from the coast. Subsp. *paradoxa* occurs from Senegal to the Central African Republic; subsp. *nilotica* is found in Sudan and Uganda with small populations in Ethiopia and Democratic Republic of Congo. The ranges of the two subspecies do not overlap, although they come within 175 km of each other at the divide between the drainage basins of Lake Chad and the Congo River to the west, and the Nile to the east and north-east.

**Uses** The seed kernel (often incorrectly called 'nut') contains a vegetable fat known as shea butter. High quality shea butter is consumed throughout West Africa as a cooking fat. Refined fat has been marketed as margarine and baking fat. It is used for pastries and confectionery because it makes the dough pliable. It is a substitute for cocoa butter, which has similar properties. Many cosmetic products, especially moisturizers, lotions and lipsticks, have shea butter as a base because its high unsaponifiable matter content imparts excellent moisturizing characteristics. Low-quality shea butter, often mixed with other oils, is a base material for soap. It is especially suitable for making candles because of its high melting point.

Shea butter is a suitable base for topical medicines. Its application relieves rheumatic and joint pains and heals wounds, swellings, dermatitis, bruises and other skin problems. It is used traditionally to relieve inflammation of the nostrils. Shea butter is given externally and internally to horses to treat sores and galls.

As a waterproofing agent, shea butter is used as daubing for earthen walls, doors and windows. The black sticky residue, left after oil extraction, is used to fill cracks in walls and as a waterproofing material.

The tree is considered to be sacred by many tribes. The oil is placed in ritual shrines and used for anointing. Waste water from shea butter production has pesticidal properties and has been mixed with stored cowpea seeds in Burkina Faso to protect them being eaten by the weevil *Callosobruchus maculatus*. The seed cake, or meal, is unsuitable for livestock because it con-

*Vitellaria paradoxa – wild and planted.*

tains anti-nutritional compounds. However, detoxified meal has been recommended as a feed filler and can be given as feed in low proportions. In Europe, the cake is utilized as a non-nutritional bulk for compound cakes. The residual meal and the husks are also potential fertilizers and fuels.

The flowers and fruits are important foods. The flowers are sometimes made into fritters. In spite of their slightly laxative properties, mature fresh fruits are commonly eaten in savanna regions. The sweet pulp of fallen ripe fruits can be fed to livestock.

The leaves are used to treat stomach-ache. They are also added to vapour baths to treat headache and as an eye bath. Leaves soaked in water produce a good lather for washing. In some areas leaves are hung in doorways to protect newborn babies, and are used in making masks.

Ground roots and bark are used to treat diarrhoea, jaundice and stomach-ache. Roots are used as veterinary medicine for horses.

Bark infusions have medicinal and antimicrobial properties, e.g. against dysentery. They are applied as an eyewash to counteract cobra venom. A bark decoction has been used in baths to facilitate childbirth and stimulate lactation among feeding mothers.

The reddish latex (gutta shea or red kano rubber) which exudes from deep cuts in the bark is made into a glue, chewed as a gum, and made into balls for children's games. Musicians use it to repair drums.

Only unproductive and unhealthy trees are cut for timber. The wood is used for support poles, house posts, roofing, rafters, flooring, domestic utensils and furniture. It is an excellent fuelwood, burning with great heat, and a source of charcoal.

Shea butter tree is an important source of honey. Beehives placed in its branches are assured a good supply of nectar and pollen. The widely collected edible and protein-rich caterpillar of *Cirina butyrospermi* feeds solely on leaves of *Vitellaria paradoxa*.

**Production and international trade** *Vitellaria paradoxa* is second to oil palm as the most important source of vegetable oil in rural areas of West Africa. The bulk of seed production is for home consumption and local trading. Nigeria is the leading producer of shea butter seeds: 355,000 t in 1999, 58% of the African production, but 10,000 t lower than in 1996. Mali and Burkina Faso are other leading producers: 85,000 t and 70,000 t/year, respectively, since 1996, followed by Ghana (55,000 t), Côte d'Ivoire (20,000 t), Benin (15,000 t) and Togo (6500 t).

In 1998, Africa exported 56,000 t seeds, valued at US$ 10.5 million, of which 60% came from Ghana. Benin's exports decreased from 15,000 t in 1995 to 5600 t in 1998, Togo had only a slight decrease from 6500 t in 1994 to 5100 t in 1998, whereas exports from Burkina Faso increased until 1998 by 7600 t. No export data have been reported for Nigeria since 1995. Processed shea butter exports in 1998 for the whole of Africa totalled 1200 t, worth US$ 571,000. Benin was top exporter (1000 t, valued at US$ 400,000), followed by Côte d'Ivoire (200 t) and Burkina Faso (30 t). Major seed importers in recent years were Belgium, Denmark, Japan, the Netherlands, Sweden and the United Kingdom.

**Properties** Shea butter from fresh seeds is white, odourless and of high quality, while that from stale seeds is dark, and tastes bitter. Approximate chemical composition of the kernel per 100 g dry matter is: fat 31–62 g, protein 7–9 g, carbohydrates 31–38 g, unsaponifiable matter 2.5–12 g. The fat consists of fatty acids, their glycerides and unsaponifiable matter. Stearic acid (30–50%) and oleic acid (41–50%) are the major fatty acids of shea butter. Linoleic, palmitic, arachidic, myristic and linolenic acids are present in small amounts. Shea butter can be a useful cocoa butter substitute because it has a similar melting point and high amounts of distearin (30%) and some stearo-palmitine (6.5%) which make it blend with cocoa butter without altering flow properties. The latter also makes shea butter an appropriate base for medicinal and pharmaceutical creams.

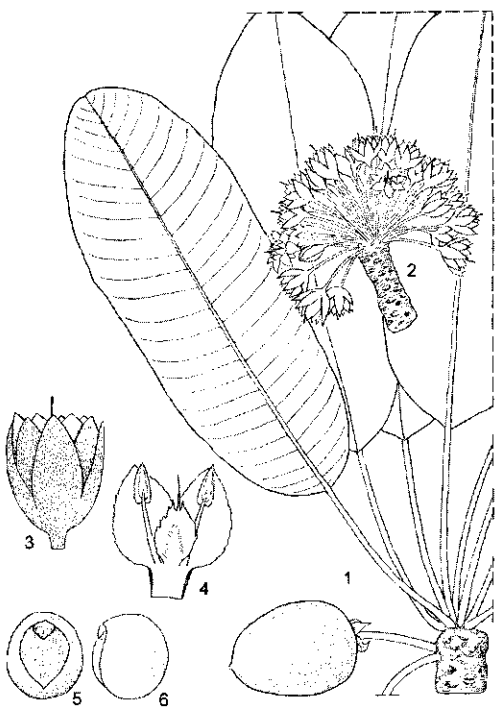
The high proportion of unsaponifiable matter, consisting of 60–70% triterpene alcohols, gives shea butter creams good penetrative properties that are particularly useful in cosmetics. Allantoin, another unsaponifiable compound, is responsible for the anti-inflammatory and healing effect on the skin. Clinical tests with patients suffering from rhinitis, and having moderate to severe nasal congestion, showed that shea butter may relieve nasal congestion better than conventional nasal drops.

Shea seed cake is a potential source of feed for livestock. Per 100 g dry matter it contains: carbohydrates 48–67.5 g, proteins 8–25 g, fat 2–20 g, fibre 5–12 g, ash 5–7 g. However, it has low digestibility and toxic properties attributed to saponins or tannins. Mouldy seeds contain relatively low quantities of aflatoxin, while commercial samples have a maximum of 20 μg aflatoxin $B_1$ per kg.

The fruit pulp contains per 100 g: glucose 1–2 g, fructose 1–2 g, sucrose 1–2 g, ascorbic acid 200 mg, Ca 36 mg, Mg 26 mg, Fe 2 mg, and trace amounts of Zn, Mn and Cu.

The wood of *Vitellaria paradoxa* is moderately heavy (density about 720 kg/m$^3$ at 12% moisture content), hard, durable and resistant to termites. It is liable to crack on drying and needs to be seasoned slowly. It is difficult to work and tends to split on sawing, but it polishes well. It glues, nails and screws well, but pre-boring is recommended to avoid splitting. Both sapwood and heartwood are resistant to impregnation with preservatives.

**Description** Small to medium-sized deciduous tree, up to 15(–25) m tall; tap root up to 1(–2) m long, lateral roots shallow, concentrated at a depth of 10 cm and extending up to 20 m outward from tree, secondary lateral roots growing downwards to the same depth as tap root; bole short, usually 3–4 m long, up to 100 cm in diameter; bark blackish, greyish or reddish, rough, deeply fissured and splitting regularly into corky squares or rectangular scales, producing white latex when cut; crown round to spindle-, umbrella- or broom-shaped; young branches initially pubescent and reddish but becoming glabrous, flowering branches stout, up to 1.5 cm in diameter, with numerous leaf scars. Leaves arranged spirally, mostly in dense clusters at the tips of branches, simple; stipules small and caducous; petiole 3–10 cm long; blade lanceolate to ovate-oblong, 10–25 cm × 4–14 cm, base cuneate or rounded to subcordate, apex rounded to subacute, entire to undulate, leathery, glabrescent to puberulous at both surfaces, pinnately veined with regularly and closely spaced veins. Inflorescence a dense fascicle at the end of a twig, consisting of (8–)30–40(–100) flowers. Flowers in the axils of scale leaves, bisexual, regular, white or creamy-white, fragrant; pedicel up to 3 cm long; sepals free, in 2 whorls of (3–)4, 1–1.5 cm long, pubescent; corolla with short tube and (6–)8 lobes about as long as sepals, contorted in bud; stamens (6–)8, inserted at top of corolla tube, free, staminodes (6–)8, alternating with the stamens, petaloid, with a filiform point; ovary superior, subglobose to ovoid, pubescent, (5–)6–8(–10)-celled, style long and slender. Fruit a subglobose or ellipsoid berry, 4–5(–8) cm × 2.5–5 cm, weight (10–)20–30(–57) g, initially green but turning yellowish-green or brown on maturity, 1(–2)-seeded. Seed globose or broadly ellipsoid, 3–5 cm × 2–3.5 cm, weight (5–)8–10(–16) g; testa rather thin, shining, with broad adaxial scar; kernel consisting of two thick, fleshy, closely adpressed cotyledons and not exserted radicle. Seedling with cryptogeal germination; epicotyl 3–4 cm long, bearing stipulate cataphylls.




*Vitellaria paradoxa – 1, tip of branch with leaves and fruit; 2, tip of branch with inflorescence; 3, flower; 4, part of corolla with staminode and 2 stamens; 5, seed in front view; 6, seed in side view.*

*Redrawn and adapted by M.M. Spitteler.*

**Other botanical information** *Vitellaria* comprises a single species. Two subspecies are recognized in *Vitellaria paradoxa*: subsp. *paradoxa* (synonym: *Butyrospermum parkii* (G.Don) Kotschy) and subsp. *nilotica* (Kotschy) A.N.Henry, Chithra & N.C.Nair (synonym: *Butyrospermum niloticum* Kotschy). Subsp. *paradoxa* has a less dense and shorter indumentum, and slightly smaller flowers than subsp. *nilotica*.

**Anatomy** Wood-anatomical description:

– Macroscopic characters:

Heartwood pale red or reddish-brown to deep, rich red with purple tinge, more or less distinctly demarcated from the whitish or pale pink to reddish sapwood; wood becoming darker when exposed to the air. Grain often interlocked. Texture fine, even. Growth rings slightly defined or absent.

– Microscopic characters:

Vessels in short radial multiples, small. Rays fine. Parenchyma in concentric bands connecting the vessel rows.

**Growth and development** Seeds of *Vitellaria paradoxa* are recalcitrant. After water absorption, the testa breaks on the micropylar side. Two days later, the fused petioles of the cotyledons emerge and elongate into a 'pseudo-radicle', containing the plumule, which grows down into the soil. The 'true' radicle develops into a taproot with corky exterior after the epicotyl has emerged. The deep tap root and secondary root system are developed during the first few years of growth. This enables the seedling to produce new shoots after drought or fire. Early stem growth is slow; branching occurs after 4–7 years. *Vitellaria paradoxa* begins flowering at 10–25 years. Early flowers may be sterile. Maturity is reached at 20–45 years. The lifespan is 200–300 years.

Growth occurs in flushes, and according to Aubréville's model. A flush starts with the formation of a short, thick shoot on which a tuft of leaves develops. Branches owe their characteristic appearance to sympodial growth, producing twigs with alternating thin, extended sections and short, compact sections. Leaves and flowers develop on the short, thick terminal section which is characterized by very short internodes and prominent leaf scars. When leaf development stops, growth of the branch continues from an axillary bud. Leaf fall, flowering, flushing and the onset of fruiting occur during the dry season. Leaves drop mostly at the beginning of the dry season. Trees are rarely completely leafless, or only for relatively short periods. Flowering occurs from the beginning to the middle of the dry season (between November and January depending on latitude). Fire may cause defoliation followed by earlier flowering. Flowers attain full size about 3 weeks after their appearance. They are protogynous; styles are exserted from the unopened flowers before the pollen matures. Pollination is by insects (e.g. bees) or by wind. About 25% of the flowers set fruit. Fruits develop in 4–6 months; maturation peaks in the rainy season. Fruiting cycles are variable, 2–5 years long.

**Ecology** *Vitellaria paradoxa* is characteristic of West African savanna but is also present in southern Sahel. Subsp. *paradoxa* grows mostly at 100–600 m altitude (mean annual temperatures 25–29°C), although it also occurs up to 1300 m; subsp. *nilotica* occurs between 450 m and 1600 m. Subsp. *paradoxa* grows in areas with mean annual rainfall of 600–1400 mm and 5–8 months dry season (precipitation < 50 mm); subsp. *nilotica* grows in areas with mean annual rainfall of 900–1400 mm, with 3–5 dry months.

*Vitellaria paradoxa* grows on a variety of soils, such as clay, sandy clay, sand, stony soil and laterites. It prefers colluvial slopes with moderately moist, deep soils, rich in organic matter.

**Propagation and planting** *Vitellaria paradoxa* is propagated by seed. Seeds should not be dried, but sown as soon as possible because they have very short viability. When fresh seed is used germination is 90–97% at 25–30°C. Storing seed at 25°C for 70 days and 140 days resulted in 96% and 88% germination, respectively. Seed can be planted directly in the field or in the nursery. Seed-beds are made of a mixture of organic compost and sand. Seeds are planted at 1–5 cm depth and 20 cm × 15 cm spacing or in polythene bags. After 1 year, seedlings are transplanted in the nursery or planted directly in the field. Those grown in polythene bags are transplanted after 1–2 years.

Vegetative propagation has only been successful experimentally. Grafting can accelerate the fruiting of *Vitellaria paradoxa*. In experiments in Burkina Faso, some grafted seedlings started to bear fruit a year after grafting. Latex exudation interferes with rooting and grafting. A 25% success rate can be achieved in grafting if the scion is soaked in water for a few hours to allow the latex to drain. Marcotting has been tried with some success; growth hormones improved the success rate.

Field spacing depends on the cropping system; recommendations vary from 25 trees per ha (20 m × 20 m) to 100 trees per ha (10 m × 10 m). Mulching and weeding encourage good seedling growth. Young plants should be protected from livestock and fires. Slow growth and late maturation have discouraged the planting of *Vitellaria paradoxa* in plantations.

**Management** Shea butter tree has been protected by farmers for many centuries in the West African savanna, particularly where cattle are scarce. Productive shea butter trees are retained when new fields are cleared, giving rise to the so-called *Vitellaria* parkland in Sudan, in which more than 40% of the trees are *Vitellaria paradoxa*. Natural regeneration is favoured by fallow of at least 5 years. Shortening the fallow period leads to insufficient regeneration. In areas of cultivation, shea butter tree is found in association with annual crops, such as pearl millet, sorghum, groundnut, cotton, cassava, yams and vegetables.

Pruning, weeding, applying manure or fertilizer, and removing dead and diseased trees can markedly increase productivity. Recommended fertilizer applications are 2.5 kg ammonium sulphate, 1.5 kg calcium phosphate and 1.5 kg potassium chloride for 10 trees. Although *Vitellaria paradoxa* is fire tolerant, its growth and fruiting are affected by fire, so trees must be protected by ring weeding. Overgrazing by livestock should be prevented.

**Diseases and pests** Two fungal diseases are potentially important: *Pestalotia heterospora* causes leaf spot, while *Fusicladium butyrospermi* causes dark patches on branches. In Ghana, *Botryodiplodia* spp. also causes leaf spot.
There are numerous insect pests, the most important being *Curimospherna senegalensis* which attacks young shoots, *Xyloctonus scolytoides* which tunnels through the bark of twigs impeding growth of leaves and flower buds, *Nephopteryx orphnanthes* which damages fruits, and *Cirina butyrospermi* which causes defoliation. Fruits are attacked by maize cob borer *Mussidia nigrivenella* and the fruit fly *Ceratitis silvestris*, which feeds on the pulp of maturing fruits. Shea butter tree is a host of the nematode *Aphasmatylenchus straturatus*, which also affects intercropped legumes. Trees are often hosts to strangler figs (*Ficus* spp.) and hemiparasitic plants (*Tapinanthus* spp.). In Burkina Faso and Mali, up to 95% of the trees are infested. Unless controlled by removing and burning affected branches, infestation will eventually kill the trees.

**Harvesting** Fruits are gathered in the wet season, usually in June–August depending on latitude. Harvesting continues for about 2.5 months. Fallen fruits are collected from the ground mostly by women and children. Picking rights depend on tenure. A woman collects 20–45 kg of fruits per day, depending on ethnic group, proximity of trees to the village, and distance between trees. Fruits are brought back to the village in head-loads of about 25 kg.

**Yield** Productivity of shea butter trees is variable. In a sample taken in Burkina Faso, the best 25% of the trees produced 60% of the yield, while the poorest 30% of trees produced little fruit. A good tree can bear on average 15–30 kg fruits per year. Productive trees may produce up to 50 kg in a good year, but then only about 15 kg in the next two years. Although a clear production cycle is not confirmed, observations show a tendency for *Vitellaria paradoxa* to give only 1 good harvest per 3–4 years. Climate, fire and management also affect yields.

**Handling after harvest** In rural areas, fruits are processed by water extraction, usually the job of women. The fruit pulp is first removed for food, or by fermentation or boiling. The seeds are then boiled and later sun- or kiln-dried. Sun-drying may take 5–10 days. Seeds are cracked using mortar and pestle, or stones; the kernels are removed by trampling. Kernels then undergo drying (either sun-drying or kiln-drying), crushing and grinding to form a paste, kneading, heating or boiling and churning. A grey, oily fat is skimmed from the emulsion, washed to remove residues and formed into balls. The fat undergoes further refinement and moulding. This traditional method of processing is inefficient and labour intensive. Mechanization, such as the use of grinders, solar kilns, kneading machines and hydraulic hand presses and modern methods involving organic solvents, screw press, filter press and hydraulic press can result in 80% extraction efficiency. Pretreating the kernel meal with enzymes (e.g. proteases and cellulases) can increase fat production by 20%.

**Genetic resources** The genetic diversity of *Vitellaria paradoxa* is being lost because of bush fires and overgrazing. It is designated as one of the African forest genetic resource priorities. It is the subject of *in situ* conservation and germplasm exploration. Local and regional germplasm collections have been made by the Institut National de l'Environnement et de Recherches Agricoles (INERA) and the Centre National de Semences Forestières (CNSF) in Burkina Faso, the Cooperative Office for Voluntary Organisations of Uganda and the International Centre for Research in Agroforestry (ICRAF) in Mali. There are also local collections; those of Ghana's Cocoa Research Institute were analysed for fruit and seed size and fat content.

**Breeding** The Cocoa Research Institute of Ghana has started a breeding programme to select and breed cultivars that establish easily in the field and have seeds with high fat content. The long juvenile phase and the difficulty of vegetative propagation of *Vitellaria paradoxa* make breeding a long-term process.

**Prospects** Shea butter tree is of great economic importance in the Guinea and Sudan savanna zones. It grows over a wide area, regenerates well, is traditionally managed and protected by farmers. However, natural regeneration and sustainability of shea nut production are threatened by agricultural intensification in the area. *Vitellaria paradoxa* has a niche in the international markets as a cocoa butter substitute

in the food, cosmetic and pharmaceutical industries. Now that the European Union allows the use of 5% cocoa butter substitutes in chocolates, new demands for shea butter may arise. However, the best opportunities for new markets may be for hydrating creams for cosmetics and pharmaceuticals.

**Major references** 2049, 5185, 5833, 5834, 5835, 5836, 5837, 5838, 5839, 5840

**Other references** 3821, 5841, 5842, 5843

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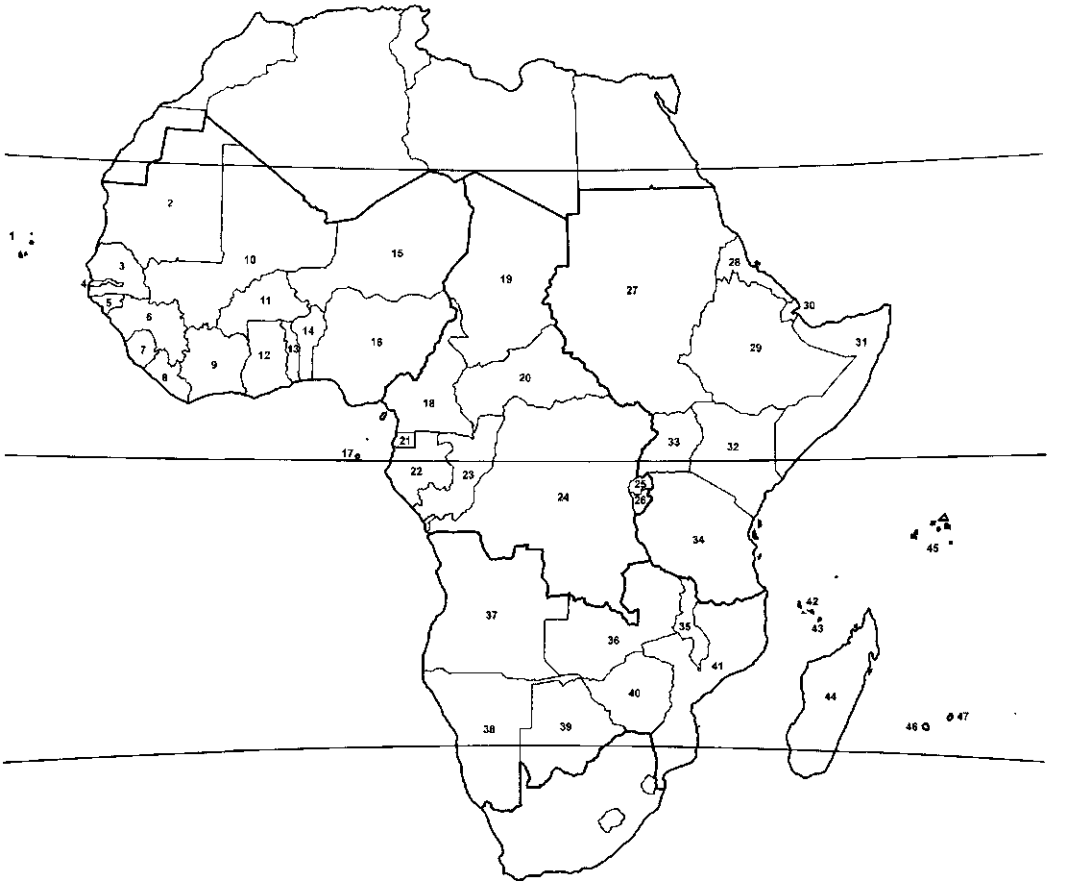

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1. Cape Verde
2. Mauritania
3. Senegal
4. Gambia
5. Guinea Bissau
6. Guinea
7. Sierra Leone
8. Liberia
9. Côte d'Ivoire
10. Mali
11. Burkina Faso
12. Ghana
13. Togo
14. Benin
15. Niger
16. Nigeria

**CENTRAL AFRICA**

17. São Tomé et Principe
18. Cameroon
19. Chad
20. Central African Republic
21. Equatorial Guinea
22. Gabon
23. Congo
24. Democratic Republic of Congo
25. Rwanda
26. Burundi

**EAST AFRICA**

27. Sudan
28. Eritrea
29. Ethiopia
30. Djibouti
31. Somalia
32. Kenya
33. Uganda
34. Tanzania

**SOUTHERN AFRICA**

35. Malawi
36. Zambia
37. Angola
38. Namibia
39. Botswana
40. Zimbabwe
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42. Comoros
43. Mayotte (Fr)
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